Growing and managing alfalfa in Canada

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FRONT COVER, top to bottom Typical alfalfa leaf; field of high-quality alfalfa; leafcutting bee pollinating a flower raceme; and a root nodule, which fixes nitrogen.

Dedicated to Hugo Gross, friend and colleague

Recommendations for pesticide use in this publication are intended as guidelines only. Any application of a pesticide must be in accordance with directions printed on the product label of that pesticide as prescribed under the *Pest Control Products Act.* **Always read the label.** A registered pesticide should also be recommended by provincial authorities. Because recommendations for use may vary from province to province, your provincial agricultural representative should be consulted for specific advice.

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Contents

Growing and managing alfalfa in Canada

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Foreword

Alfalfa, the "queen of the forage crops," comes close to the ideal cultivated crop in not only maintaining but improving the soil on which it grows, and in providing abundant nutritious sustenance as animal and human food. Alfalfa is the most popular forage legume grown in Canada and on a worldwide basis. It is adapted to a wide diversity of soil and climatic conditions and is grown in all provinces. It is estimated to be grown on 4–5 million ha in Canada. Alfalfa produces forage with excellent nutritional qualities and high digestibility—it is the standard of excellence against which all other forage crops are compared. Alfalfa will probably play an increasingly important role in the future, with supplies of fossil fuels diminishing and cost of nitrogen fertilizers increasing. The alfalfa plant is a miniature nitrogen factory, tapping the limitless nitrogen supply in the air and converting it into a form readily used by the plant. Furthermore, alfalfa is acknowledged by plant scientists to produce more protein per hectare than any other known crop, and its protein is almost equal to animal proteins in balance and quantity of amino acids that are essential in animal and human nutrition.

Because of the widespread interest in and use of alfalfa, this publication has been prepared by alfalfa researchers from across Canada. The information it contains is comprehensive and includes botanical and cultivar descriptions, general management and agronomy of the crop, and sections on insects and diseases with appropriate color photos to aid in their identification. The publication is intended to serve mainly as a comprehensive guide for farmers and extension workers in growing and managing alfalfa throughout Canada.

Special regional recommendations should be obtained from provincial departments of agriculture, from universities, or from research stations.

General guidelines to growing alfalfa are:

- Seed only the cultivars recommended for your area that have the advantage of higher yields, better disease resistance, and improved characteristics.
- Seed shallow into a well-prepared firm and weed-free seedbed.
- Seed in early spring.
- Inoculate the seed immediately before seeding.
- For seed production leafcutting bees must be used.

Trade names are used in this publication solely to provide specific information. This does not constitute endorsement by Agriculture Canada or a preference over similar or other products not mentioned.

Introduction

Alfalfa, the "queen of the forage crops," is the most popular and important forage legume grown in Canada. Called lucerne in many countries outside North America, it is thought to have originated in southwestern Asia with Iran as the geographic center of origin. Alfalfa was cultivated long before recorded history and is now found growing wild from the subtropical to the subarctic areas of the world. The oldest historical record indicates that alfalfa was cultivated and prized as a highly nutritious animal feed in Persia and Turkey more than 3300 years ago. The first recorded attempt to grow alfalfa in the United States was in Georgia in 1736. However, it was not until 1850, when "Chilean clover" was introduced to California from Chile, that its rapid expansion and growth in popularity began.

Alfalfa was first introduced to Canada in 1871. A shepherd accompanying some sheep imported from Lorraine, France, brought 1 kg of seed to a farm in Welland, Ont. This strain subsequently became known as Ontario Variegated and is still grown occasionally in Eastern Canada.

Successful culture of alfalfa in northern United States and Canada was not possible until the more hardy variegated strains of *Medicago media* (purple-flowered *M. sativa* × yellow-flowered *M. falcata*) were introduced. The earliest and most important of these introductions was by the German immigrant Wendelin Grimm, who brought 8 kg of *M. media* alfalfa seed from his native Germany when he settled in Minnesota in 1857. After several successive severe winters in Minnesota, a very hardy strain eventually resulted and Grimm's alfalfa soon advanced successful alfalfa culture into the northern states and Canada. Further selection for winterhardiness by professors John Bracken and

L. E. Kirk of the Field Husbandry Department, University of Saskatchewan, resulted in the distribution in 1926 of Breeder seed of the winter-hardy strain 666 of Grimm alfalfa.

Alfalfa is grown in every province of Canada. Although there is no reliable estimate of its total area, it was recorded by the 1976 Census of Canada that alfalfa was grown alone or in alfalfa–grass mixtures for hay on 2 614 000 ha. There is probably an equal or greater area used for pasture. In addition, a considerable area is devoted to the crop for green manure, silage, dehydration products, and seed production. Hence alfalfa is probably grown on 4–5 million ha in Canada.

Characteristics

Alfalfa, *Medicago* spp., is a bushy perennial legume that grows to a height of 60–100 cm. The leaves are 1.3–3.8 cm long and consist of three leaflets, with smooth edges, slightly toothed at the tip. The leaflets vary from nearly round to ovate (typical of *M. sativa*), through to obovate and lanceolate (typical of *M. falcata*) (Figure 1). Stems are slender, either solid or hollow. Flowers growing from leaf axils in clusters of 10–20 florets are usually blue or purple (*M. sativa*), but may be white or yellow (*M. falcata*) and occasionally bronze and green. Seed pods vary from sickle- or crescent-shaped to coiled in one to three spirals (Figure 2). The sickle pod has been almost eliminated by selection because it contains few seeds and shatters easily. Alfalfa seeds are small (465/g).

The roots of alfalfa are of four general types: tap, branch, rhizomatous, and creeping (Figure 3); all penetrate deeply, 3–9 m into the soil. Tap-rooted types have a main root and a narrow, protruding crown. Branch-rooted types have a moderately wide crown and a number of primary roots. Rhizomatous-rooted types spread from the broad crown by horizontal stems that may root at the nodes. Creeping-rooted plants have low crowns and develop horizontal rootstalks from primary roots 10–20 cm below ground. Shoots, which may become independent plants, develop from these rootstalks. The rhizomatous- and creeping-rooted types have a more protected crown and develop new roots more readily than the tap- and branch-rooted types. Creeping-rooted plants are more persistent under pasture management and general adverse conditions such as extreme cold and trampling by livestock.

Alfalfa has a terminal growing point; that is, growth develops at the tips of the stems and branches. When the growing points are cut, or damaged by grazing, frost, sprays, insects, or diseases, growth continues from leaf axillary buds below the cutting point. New growth is initiated from the crown buds of the root.

Alfalfa has the ability to tap the limitless nitrogen supply in the air through a symbiotic relationship with special soil bacteria of the species *Rhizobium meliloti* Dangeard. These rhizobium bacteria produce root nodules on the plant (Figure 4) and convert atmospheric nitrogen into a form readily used by the plant. This conversion process is called symbiotic nitrogen fixation. To ensure that the nitrogen-fixation process is active, alfalfa seed should always be

inoculated just before planting (see subsequent sections on seeding and soil improvement). In regions where the soil is near neutral to slightly basic, the rhizobium bacteria persist well. However, acid soils that are low in lime content need liming before seeding, and special acid-tolerant rhizobium bacteria may be required for inoculation of the seed.

Adaptation

Alfalfa is adapted to a wide diversity of soil and climatic conditions in Canada. It is particularly well adapted to deep, well-drained and near-neutral soils. Alfalfa does not grow well in strongly acid soils and the application of lime is often necessary for successful culture. This crop is useful on slightly to moderately saline areas. Alfalfa has very little tolerance for poor drainage conditions. Poor drainage combined with extremes in climate or with plant diseases adversely influences the length of stand survival. Alfalfa must be winterhardy to survive in Canada. In the Prairie Provinces alfalfa cultivars must be very hardy because of long, cold winters, variable snow covering, and often very dry conditions. In Eastern Canada and British Columbia, where the climate is less severe and moisture more plentiful, medium-hardy Flemish cultivars are preferred because of their rapid recovery and higher yields. Flemish alfalfa is earlier and usually has greater cold tolerance than other common (*M. sativa*) alfalfas. However, winterkill of all alfalfas occurs from icing-over or heaving of plants on poorly drained areas and heavy soils, and from alternate freezing and thawing.

Optimum temperatures for growth of alfalfa are 15–25°C during the daytime and 10–20°C at night; growth is restricted above 30°C. Alfalfa produces high yields of good-quality forage and is hardy, long-lived, and suitable for hay and pasture. It does well either alone or in mixtures with several other forage crops. A stand can produce one cut of hay in drier areas and up to four cuts in moister, longer-season areas.

In regions where moisture is deficient, alfalfa responds well to irrigation and usually produces over 9 t/ha. Alfalfa also produces high yields on soils where it can penetrate to the water table and obtain water during periods of drought. Water tables 3–5 m below the surface can be readily reached by alfalfa roots.

Cultivars

Alfalfa cultivars are licensed in Canada on the basis of results from tests for yield, winterhardiness, disease and insect resistance, and other agronomic characters. Any cultivar, once licensed, is eligible to be sold anywhere in Canada under its cultivar name. However, few cultivars are adapted to all regions of the country, and therefore you should follow the recommendations of your province or region in choosing a cultivar.

The potential production of alfalfa depends largely on the rate of recovery after cutting. Under ideal growing conditions, cultivars that recover quickly produce more than those that recover slowly. Therefore, select a cultivar that recovers quickly, but make sure that the climate is favorable for the one you

choose. Where the climate is less favorable, choose slow-recovering cultivars, because they are generally more tolerant of cold and dry conditions. As a rule, grow the cultivar with the most rapid recovery, provided it persists and withstands the winters satisfactorily.

The cultivars listed in Table 1 appeared on provincial recommendation lists at the time this publication was being prepared. New cultivars are released periodically by public and private agencies, and therefore it is important to keep informed of changes in the recommendations. Seed of some older ones such as Grimm, Du Puits, Ranger, and Rhizoma may still be available in certain parts of the country, although these no longer appear on recommendation lists. Seed only the recommended cultivars, which have the advantage of higher yields, better disease resistance, and improved characteristics over older ones.

Use only pedigreed seed of the recommended cultivars to be sure of a proven, high-quality product that has good germination, is free from noxious weed seeds, and is adapted to your particular region. Use of nonpedigreed seed is not recommended, because such seed (i.e., Canada No. 1) cannot be identified by cultivar name.

Seeding

Always use pedigreed seed of a recommended cultivar. Choosing a recommended cultivar provides maximum yields and economic returns on your investment.

A carefully prepared seedbed is the key to successful alfalfa establishment. A good seedbed should be firm and free from weeds, and have moisture near the surface. A firm seedbed may be prepared by using a packer, rod weeder, or a harrow, if the soil is very loose. A firm seedbed may also be provided by undisturbed stubble or by natural packing of fallow land by rain or snow. The heel of your shoe should not sink more than 1 cm into the soil on a well-prepared seedbed. Soil moisture within 2.5 cm of the surface is essential: the small seedlings would have difficulty emerging through the soil if seeds were planted deeper to reach moisture. Preseeding tillage should be shallow to avoid loosening and drying of the soil. Packing and firming of the soil allows moisture to move upward (the "blotter effect") and maintains moisture closer to the soil surface. On heavy clay, the soil should not be worked smooth because it may crust after rain and thus prevent seedling emergence.

Shallow seeding ensures good stands. One of the most common causes of failure in new seedings is sowing too deep. Plant at a depth of 1–2 cm. Seeds placed below 2.5 cm have difficulty in emerging and developing a satisfactory stand. This is a result of insufficient energy (food reserves) in the small seed to produce a seedling capable of reaching the soil surface in a robust state. If seeding equipment penetrates too deeply into the soil, have depth control flanges fitted onto the discs of the seed drill. Broadcast seeding is not recommended in the dry areas of the Prairie Provinces because the soil surface seldom remains moist long enough to allow the seeds to germinate and become established.

The best stands are obtained from early spring seeding; seed as soon as the land can be worked. Early seeding is particularly important on sandy and light loam soils because they have a low moisture-holding capacity. Early seeding takes advantage of spring moisture conditions and allows alfalfa seedlings to emerge and establish themselves before the first flush of weed growth. Seeding in late summer (mid-August) in the Prairie Provinces gives less than a 50% chance of successful stand establishment because of lack of moisture and possible killing frosts in early September. However, in Eastern Canada and British Columbia late-summer seedings are quite successful, as the fall season is generally long enough to allow the plants to develop sufficiently before winter. Well-developed plants stand the best chance of winter survival. In the Prairie Provinces, seeding may be done near the end of October, when it is too cold for the seeds to germinate; the practice is known as dormant seeding. This late-season seeding is often practiced when soil is difficult to work in early spring because of excess moisture. Thus the seed is in position to develop in the following spring, when moisture and temperature conditions are favorable for germination and seedling development.

Seeding rates and methods vary considerably across Canada. In Eastern Canada and British Columbia, alfalfa in pure stand is seeded at 12–14 kg/ha and in mixture with grasses at 9–11 kg/ha. It is usually seeded with a Brillion-type seeder or forage seeding attachment, which provides a solid stand. In the Prairie Provinces, however, alfalfa in pure stand in the semiarid areas is seeded at 4–7 kg/ha in rows 30–60 cm apart. In mixture with grasses, alfalfa is seeded at 1–4 kg/ha in rows 30–90 cm apart. On irrigated land, seed alfalfa at a rate of 9–11 kg/ha, either in rows 15–20 cm apart with a forage seeder, or broadcast. Consult with provincial authorities for local recommendations in your area.

As a general rule, alfalfa should be seeded alone, without a companion crop (refer to the following section on weed control).

Alfalfa seeds require inoculation. This is done by coating the seed with a prepared culture of the required strain of *Rhizobium meliloti* bacteria. Soils may contain rhizobium bacteria from a previous crop, but seed inoculation ensures nodulation. Keep inoculum in airtight containers in a refrigerator until used to avoid drying, which reduces viability of the bacteria. Inoculate seed immediately before seeding to avoid drying. If planting is delayed, the inoculated seed may be stored for a short period in a cool, dark place. After 3 or 4 days it is advisable to reinoculate. Acid soils should be first treated with lime before inoculated seed is sown. For detailed information on methods of applying inoculum, refer to Agriculture Canada publication 1299, *Legume inoculation*, and to instructions given on the culture packages.

In summary, the keys to successful seeding and establishment are:

- Use pedigreed seed of a recommended cultivar.
- Prepare a firm seedbed.
- Seed shallow, less than 2.5 cm deep.
- Seed as early as possible in the spring.
- Inoculate the seed immediately before seeding.

Table 1. Alfalfa cultivars recommended in Canada

Cultivar	Provinces for which recommended*						
	B.C.	Alta.	Sask.	Man.	Ont.	Que.	Atl.
Excellent cold tolerance							
Anik	x	x					
Drylander	x	x	x				
Heinrichs		x	x				
Kane	x	x	x				
Rambler	x	x	x	x			
Rangelander	x	x	x	x			
Roamer	x	x	x				
Very good cold tolerance							
Algonquin	x	x	x	x	x		x
Beaver	x	x	x	x			
Peace	x	x					
Spredor 2		x					
Trek		x					
Good cold tolerance							
Anchor	x	x	x	x	x	x	x
Angus		x		x	x	x	x
Answer					x		
Apica		x	x		x	x	x
Apollo				x	x	x	
Blazer					x		
Ceres	x				x		
Chimo				x			
Citation		x			x	x	x
Classic					x		
DeKalb 120		x	x		x	x	
DeKalb 130					x		
Glory					x		
Hunter					x		
Iroquois					x	x	x
Magnum					x		
OAC Minto					x		
Pacer	x	x			x	x	x
Peak					x		
Pickstar				x	x		
Pioneer 524		x			x	x	
Pioneer 526					x		
Pioneer 532		x			x	x	
Primal					x		
Regal					x		
Saranac	x				x	x	x
Thor	x	x		x	x	x	x
Titan		x			x	x	x
Trident					x		
Trumpetor	x	x			x		
Turbo					x		
Valor					x		
Vernal	x	x	x	x	x	x	
Vertus	x			x			
Vista		x		x	x		
Warrior						x	
Weevlcheck					x		
WL215					x		

* Changes in recommendations on cultivars occur frequently. Consult provincial extension authorities for the latest information on such changes.

†R = more than 51% resistant plants; MR = 36–50% resistant plants; MS = 21–35% resistant plants; S = less than 20% resistant plants.

Country of origin and Canadian distributor	Recovery after cutting	Resistance† to bacterial wilt	Other characteristics
Canada (public)	very slow	S	*M. falcata* strain
Canada (public)	slow	R	creeping rooted
Canada (public)	medium	R	creeping rooted
Canada (public)	slow	R	creeping rooted
Canada (public)	slow	MR	creeping rooted
Canada (public)	slow	S	creeping rooted
Canada (public)	slow	R	creeping rooted
Canada (public)	medium	R	
Canada (public)	medium	R	
Canada (public)	medium	S	tolerance of multiple cuts
USA (Northrup King)	slow	R	creeping rooted
Canada (public)	medium	R	R to stem nematode
USA (OSECO)	rapid	R	
Canada (public)	rapid	R	
USA (Speare Seeds)	rapid	R	R to *Phytophthora*
Canada (public)	rapid	R	
USA (OSECO, PAG Seeds)	rapid	R	MR to *Phytophthora*
USA (OSECO)	rapid	R	MS to *Phytophthora*
USA (Speare, PAG Seeds)	rapid	R	
USA	rapid	R	
USA (Maple Seeds)	rapid	R	
USA (UCO)	rapid	R	
USA (DeKalb)	medium	R	MR to *Phytophthora*
USA (DeKalb)	rapid	R	
USA (Speare Seeds)	medium	R	
Canada (Otto Pick & Sons)	rapid	R	
USA (public)	medium	R	
USA (Rothwell Seeds)	medium	R	
Canada (Speare Seeds)	rapid	R	
USA (Bishop Seeds, OSECO, General Seeds Co)	rapid	R	
USA (OSECO)	rapid	R	MR to *Phytophthora*
USA (Pickseed)	medium	R	
USA (Pioneer)	medium	MR	
USA (Pioneer)	medium	R	
USA (Pioneer)	rapid	R	
USA (King Grain)	medium	R	
USA (UCO)	rapid	R	
USA (public)	rapid	R	
USA (Northrup King)	rapid	R	
USA (OSECO)	medium	R	
USA (PAG Seeds)	rapid	R	R to *Phytophthora*
USA (Northrup King)	rapid	MR	MS to *Verticillium*
USA (Otto Pick & Sons)	rapid	R	MR to *Phytophthora*
USA (Rothwell Seeds)	medium	R	
USA (public)	medium	R	
Sweden	rapid	S	MR to *Verticillium*
USA (Pickseed)	rapid	R	
USA (Northrup King)	medium	S	
USA (UCO)	medium	R	
USA (King Grain, Speare Seeds)	medium	R	

Weed control

Annual weeds can severely damage seedling stands of alfalfa. Weed competition can reduce alfalfa growth in the seedling year so that plants entering dormancy in the fall are small and weak, which reduces yields in the following year. If there is a very heavy growth of annual weeds, alfalfa seedlings may not survive. To introduce as few new weeds as possible to a field, use pedigreed seed and to minimize the risk of a severe weed infestation, use the cleanest land available for the alfalfa crop.

Companion crops are often used for weed control and to provide some crop return in the year of establishment. Remember that a more productive and stronger seedling stand usually results when a companion crop is not used. However, if you do plant a companion crop, sow it at one-half or less the normal rate as a first operation; this further packs and firms the soil. Then seed the alfalfa at the required shallow depth (1–2 cm), either crosswise or in alternate rows, which minimizes competition between the more vigorous companion crop seedlings and the delicate forage seedlings. Cereals such as wheat, oats, and barley are the most commonly used companion crops. They should be removed as hay or by grazing in midsummer to allow the alfalfa a long, unhindered period to grow and develop before winter.

Weed control in a companion crop–alfalfa stand is difficult, because both crops must be tolerant of the control measures used. Alfalfa seedings have moderate to good tolerance for most herbicides used to control grassy weeds, and several of them are registered for this use. Some herbicides, such as Triallate (Avadex B.W.), barban (Carbyne, Wypout), flamprop-methyl (Mataven), difenzoquat (Avenge), and diclofop-methyl (Hoe-grass), can be used with some cereal crops. Other herbicides, such as EPTC (Eptam), trifluralin (Treflan), asulam (Asulox-F), and fluazifop-butyl (Fusilade), will damage cereals severely, but can be used with some oilseed companion crops. Of the herbicides used to control broad-leaved weeds in cereals and oilseed crops, dicamba (Banvel), chlorsulfuron (Glean), cyanazine (Bladex), picloram (Tordon), and linuron (Lorox, Afolan), will kill alfalfa seedlings, and 2,4-D, MCPA, bromoxynil (Pardner, Torch), metribuzin (Lexone, Sencor), and propanil (Stampede) can cause severe damage. The herbicide 2,4-DB usually gives good control of a range of broad-leaved weed seedlings with little or no damage to alfalfa. If weeds of the mustard family are a particular problem, replacement of some of the 2,4-DB with a small amount of MCPA will improve performance. Alternatively, 2,4-D, MCPA, or bromoxynil have been used successfully where a thick weed canopy protected the alfalfa seedlings from direct contact with the herbicide.

When alfalfa is seeded alone, EPTC or trifluralin incorporated into the soil before seeding controls grass seedlings and some broad-leaved weed seedlings. An application of 2,4-DB may be needed after the alfalfa has developed one to three leaves to control weeds resistant to the preplant herbicides. Alternatively, most weed seedlings can be controlled by applying tank mixes of 2,4-DB and asulam when the weeds are small and the alfalfa has between one and three leaves. When freed from weeds and unhindered by a companion crop, alfalfa can grow enough in the seedling year to produce one or two cuts of forage, depending on the area and moisture conditions.

Weeds can also be controlled by mowing. Wild oats or volunteer cereals can be included in silage. Weeds not suitable for feeding should be cut at an early stage of growth with a mower that does not leave a swath. Alfalfa seedlings will be killed if a swath is thick enough to block light. Mow at a height that removes most leaves from the weeds, that is, 8–10 cm above the ground. Mowing too high encourages the weeds to branch out and grow back.

Except in wide-row spacing for seed production, established alfalfa competes strongly with weeds. With an alfalfa population of 30–40 plants per square metre, most weeds remain small and are only a minor component of the crop. Some annual weeds can be controlled with 2,4-DB applied at the one- to three-leaf stage of the crop or on regrowth after cutting or grazing. A similar treatment in late fall, when the alfalfa is dormant, controls winter annual broad-leaved weeds. Do not use 2,4-D on established alfalfa. Even when 2,4-D is applied to dormant alfalfa or to plants with apparently no active visible growth, damage often appears during the next growth period, and yield and quality of forage are reduced. On the other hand, alfalfa has some resistance to 2,4-D, and the chemical cannot be relied on to kill well-established plants where eradication of the alfalfa is the objective.

Simazine (Princep), terbacil (Sinbar), metribuzin, and propyzamide (Kerb) are registered for use on established alfalfa. They are applied to the alfalfa stubble in late fall when the soil is cold and alfalfa is dormant. Propyzamide kills seedling grasses and suppresses established grasses such as quack grass for one growing season. The other three kill all annual and winter annual seedlings. Terbacil and metribuzin also gives some control of established dandelion and sow thistle when applied at the maximum recommended rates. All four herbicides leave residues in the soil that may damage newly seeded crops for up to 2 years after herbicide application.

Note: A herbicide is registered only for specific uses and sometimes only for a specific region of Canada. Many herbicides leave residues in or on treated plants for some time. Feeding alfalfa containing these residues to milk- or meat-producing animals is not allowed. The use of a herbicide outside the registered uses is unwise, is not recommended, and can be illegal. Furthermore, provincial guides may not recommend a particular registered use because it causes too much damage to the alfalfa under local conditions. Herbicide registrations and recommendations change frequently. Your provincial guide to weed control is updated each year and contains the most recent recommendations for all products suitable for your area. For any specific product, the label or the container has on it the currently registered uses, the maximum rates recommended, any restrictions to the use of the crop after treatment, the precautions you should take for your own safety, and other useful information. **Read it.**

Fertilizers

The first step in proper fertilization of alfalfa is a soil test. General recommendations on fertilizer use are available from bulletins in all provinces. The requirements for fertilizer and the response of the alfalfa crop to fertilizer applications vary according to soil properties, water supply (irrigated or dryland),

age of stand, and the type of management followed. Consideration of all factors, combined with information from soil tests, takes much of the guesswork out of the fertilization program.

Alfalfa, when properly inoculated and managed, obtains nitrogen from the nitrogen-fixing bacteria that develop nodules on the roots. These organisms, using energy obtained from the alfalfa, fix atmospheric nitrogen. Seedlings may require small amounts of additional nitrogen during the establishment period until they become nodulated and fixation of nitrogen begins. Too much nitrogen inhibits nodule formation. In alfalfa–grass mixtures, nitrogen fertilizer may be required to maintain a productive grass crop because alfalfa cannot transfer nitrogen directly to it. A mixture that contains at least one-third alfalfa or more should be fertilized as would be recommended for a pure alfalfa stand.

To maintain alfalfa at a high level of production, fertilization with phosphorus is required in most regions of Canada. It is particularly important in the seeding year to ensure good root development and seedling establishment, but it is also essential for maintaining high production of alfalfa throughout the life of a stand. Because phosphorus moves very slowly in the soil it is a good practice to place at least a part of the application in easy reach of the plant roots. For seedling establishment, phosphorus can be broadcast before seeding and worked into the soil at a depth of 7–10 cm, or it can be side-banded slightly below or to one side of the seed at time of seeding. Response to preseeding broadcast fertilization is poor under very dry conditions. On established stands the fertilizer must be applied as a topdressing. In some regions, broadcasting a large amount of phosphorus at seeding should be sufficient for the crop for several years. However, greater uptake and higher phosphorus levels in the forage are obtained with annual applications at recommended rates. In acid soils and soils high in calcium, annual phosphorus topdressing is recommended, because the element is rapidly tied up and is unavailable to the plants.

Potassium can be a major limiting factor in alfalfa production because the crop feeds heavily on this element. It plays a vital role in many plant functions and affects such processes as storage of food reserves and development of cold hardiness in the fall. Most soils in the Prairie Provinces are naturally high in potassium. However, many of the coarse-textured and well-drained soils of the prairies, and most of the soils east of the Great Lakes and in the coastal areas of British Columbia, are deficient in potassium for alfalfa production. Where a soil test indicates the need for potassium, the fertilizer should be incorporated into the seedbed before planting. A measurement of the potassium level of the forage at harvest or a soil test, or both, should be carried out in subsequent years to determine the need for additional potassium. Deficient levels of soil potassium have been found to be associated with increased winter injury. On the other hand, adequate levels of soil potassium were found to enhance nitrogen fixation and thus increased protein content of the forage. On established stands the element should be applied as a topdressing.

Sulfur is deficient in some Gray Luvisols and Dark Gray Luvisols in the Prairie Provinces and in many areas of interior British Columbia. Sulfur is an important element in nitrogen fixation and protein synthesis. Deficient levels of soil sulfur result in poor seed set of seed production stands. Sulfur may be applied at seeding as a broadcast and incorporated treatment or on established stands as a topdressing.

Most micronutrient deficiencies in alfalfa can be detected by soil tests or tissue analyses. Boron deficiency is one of the commonest, especially in the Atlantic Provinces but also in Quebec, Ontario, and British Columbia, and it can cause serious reductions in crop yield. Molybdenum deficiencies tend to appear most frequently in acid soils and have been recorded in the Atlantic Provinces. Deficiencies of other micronutrients, such as iron, copper, zinc, or manganese, are comparatively rare.

The difference between deficient levels and toxic levels of most micronutrients is very small, and therefore extreme caution should be used in applying micronutrient fertilizers. They should be used only when and as recommended by a soil specialist or qualified agrologist.

Lime is generally referred to as a soil amendment rather than a fertilizer because its main function is to correct soil acidity, although it does contain plant nutrients and makes other soil nutrients more available. Alfalfa is very sensitive to soil acidity because the microbial fixation of atmospheric nitrogen is inhibited in very acid soils. Alfalfa's yield is usually reduced when the soil pH is 6.0 or lower. Under most situations the best pH for alfalfa production is between 6.5 and 7.5. Liming of the predominantly acid soils of the Atlantic Provinces, Quebec, Ontario, and coastal British Columbia is essential. Soil acidity occurs on certain soils in central Alberta and in the Peace River region of Alberta and British Columbia. The need for lime can best be determined by a soil test. Lime reacts slowly with soil and is best applied during the summer or fall before an alfalfa crop is seeded. It should be thoroughly incorporated into the soil to a depth of 15 cm. When large quantities of lime are required for strongly acid soils, it is recommended that half the total amount be incorporated during each of two separate operations.

Abnormal leaf or plant symptoms often occur when certain nutrient deficiencies occur in the soil. Refer to the following chart as an aid in identifying the deficient soil element. Keep in mind, however, that a soil or plant tissue analysis provides the final answer for the deficient (or toxic) element.

Element	**Deficiency symptoms**
Boron (B)	Terminal leaves reddened and yellowed; often referred to as "yellow top." Internodes of terminals remain short so that leaves form a rosette, followed by death of terminal bud while lower leaves and branches remain green.
Calcium (Ca)	Mainly on acid soils. Plants are light green and stunted, stands are thin. Youngest petioles may collapse. Leaf margins die commencing on leaflet tips of immature leaves, which are initially blue green, then turn gray white. The affected margins curl up to form a characteristic funnel of the top of each leaflet. Aluminum and manganese toxicity may also occur on highly acid soils.
Copper (Cu)	Terminal leaf petioles show epinastic curvature (backward folding of leaflets along petioles), followed by withering and death of leaflets.

Iron (Fe)	Deficiency occurs rarely. Upper leaves first become yellowed between veins, later bleached yellow. Usually occurs only when soil has pH above 7.5, excess carbonates, and high moisture.
Magnesium (Mg)	More prevalent on acid, sandy soils and in wet seasons because magnesium is readily leached. Leaflets show yellowing between veins. Leaf margins are initially green, later become yellow and die. Symptoms progress from older to younger leaves.
Manganese (Mn)	Mn deficiency most evident on alkaline soils, especially those high in phosphorus. Initial symptoms are reduction in growth and yellowing in youngest leaves. Yellow shows first between veins, which remain green. Later, small light brown dead areas appear. Mn toxicity can occur in acid soils. Older leaflets become yellow around margin and small dead spots may develop.
Molybdenum (Mo)	On some acid soils rich in iron. Leaflets may show whitening of tips and wilting. Flowering usually restricted. Symptoms may also resemble nitrogen deficiency.
Nitrogen (N)	Leaves yellow, roots poorly nodulated, long and fibrous, plants stunted.
Phosphorus (P)	Symptoms often not well defined. Top growth stunted, stiff and erect, roots small and light brown. Leaves small and abnormally dark green. Leaflets fold together and undersides are purplish. Oldest leaves turn yellow and die.
Potassium (K)	Symptoms first appear on the older leaves as white spots (speckled), later dead areas develop around the outer edges of the upper leaflets. Under severe deficiency, size and number of spots increase and the leaves become brittle and dry, the lower leaves dropping.
Sulfur (S)	Yellowing of leaves, frequently observed on younger leaves first. Plants appear yellow and stunted; symptoms similar to phosphorus and nitrogen deficiency.
Zinc (Zn)	Occurs rarely. First symptom is upward curling of the youngest leaves. Deficient plants grow slowly and older leaves become slightly yellowed, then plants die from the top downward. New leaves, particularly those on tillers at the base of the plant, are progressively smaller and stiffer and their margins tend to roll inward.

Air pollutant damage	Alfalfa is sensitive to high concentrations of smog, sulfur dioxide, and ozone in the air. Symptoms range from yellowing of veins to yellowing of the entire leaf. Older leaves are more sensitive than younger leaves. Damage is most frequent near urban or industrial areas.

Crop management and winterkilling

Management to produce a high-quality product economically includes selection of cultivars; meeting fertility requirements; proper cutting schedules; and weed, disease, and insect control. Proper management throughout the life of the stand is essential because what happens in one year affects production in the following year. Autumn management of the alfalfa crop is probably the single most important aspect of management, affecting the health, vigor, and persistence of alfalfa.

Alfalfa, like all other perennial legumes, stores food reserves in its roots during the fall. Such food makes the plant resistant to low winter temperatures and is used to initiate new growth in the spring and after each harvest. Each region has a period in the fall when cutting or grazing weakens plants to the level where large numbers may be winterkilled or later yields may be greatly reduced. This period is known as the "critical fall harvest period," and is generally 4–6 weeks before the first killing frost for your area (consult your provincial authorities). Leaf growth is needed during the critical fall period to synthesize carbohydrates for storage in roots and crowns. If fall cutting is practiced, the carbohydrate reserves in the roots are used to initiate new plant growth. As a consequence, plants may go into the winter low in essential food reserves. Having large food reserves in the roots and crown does not ensure that plants will survive the winter, but carbohydrates are the main source of energy for overwintering, and plants low in these food reserves are most likely to be injured or killed. Cutting after a killing frost is less hazardous than cutting before that time. Late-fall cutting, however, removes the stubble that would catch and hold snow; the latter acts as an effective insulation blanket to protect the alfalfa during winter and early spring, thus providing additional insurance against winterkilling.

Stands that have been winter-injured need conservative management to keep them in a productive condition. Winter-injured plants are usually slow to start growth in the spring and are weak in appearance, yellowish in color, and poor in number of shoots. Most winter-injured plants of disease-resistant cultivars recover to near full production if the first cutting is delayed to the late bloom stage. Cutting at an immature stage may kill winter-injured plants or keep them in a weakened condition. However, delaying the cutting until full bloom allows the plants to heal their winter-injured tissues.

Winterkilling of alfalfa may be caused by cold alone, or low temperature may interact with a great many other factors, such as:

- Weather that is unfavorable for hardening off the plants in the fall.
- Alternate freezing and thawing of the ground during the winter or early fall.

- Surface icing during the winter or early spring.
- Winters that are longer than the normal dormancy period.
- Long periods of drought in the summer and fall, causing plants to dry out before or soon after winter starts.
- Disease infection, causing weakening of the plants. Well-nourished alfalfa stands are better able to resist and recover from the ravages of diseases often associated with winterkilling.
- Poor management during the growing season and in the fall, resulting in plants going into the winter without adequate root reserves for the long period of dormancy.
- Choice of a nonhardy cultivar.

It is difficult to determine the exact cause of winterkilling. The best safeguard is to grow winter-hardy cultivars wherever winter injury occurs often (Figure 5).

Crop uses

Hay and silage

Alfalfa harvested as hay or silage can produce high yields of the most palatable forage for farm animals. At the same time it produces forage with excellent nutritive qualities and high digestibility. To obtain maximum returns from alfalfa, correct management in growing, harvesting, and storing the crop is essential. Alfalfa is usually cut once or twice each year in the Prairie Provinces, while in the moister areas of British Columbia, Ontario, Quebec, and the Atlantic Provinces, three or four harvests are possible. Alfalfa in pure stands produces high-protein hay or silage to supplement corn silage as an economical farm-grown dairy ration. However, its main use is as a roughage for farm livestock. It is obvious that management must be tailored to the region in which the crop is grown and to the intended use.

Time of cutting As the alfalfa crop progresses through the vegetative, bud, and flowering stages, important changes take place in some of the quality components; for instance, protein content decreases, digestibility decreases, and dry-matter yield increases. If the alfalfa is to be used as a protein supplement, cutting at the early bud stage is most appropriate; if it is to be used as the main roughage in a ration, cutting at the 10% bloom stage is recommended.

Preservation The objective is to preserve the highest possible proportion of the nutritive value of the standing crop. At cutting time as much as 50% of the dry-matter yield and 70% of the protein yield are contained in leaves. Leafiness is associated with quality. Aim to preserve as high a proportion of the leaves as possible. Leaf loss is a problem, particularly when alfalfa is preserved as field-cured hay. Leaves may be lost because they dry faster than stems, become brittle, and break off, or they may lose their nutritive value because

of adverse weather. Preserving alfalfa as silage reduces the chances of significant leaf loss. Use hay conditioners that crush the stems and allow faster and more uniform drying to minimize leaf losses.

Storage At cutting time, alfalfa contains 70–80% moisture. For safe storage as hay the moisture content must be reduced to 20–25%. Hay stored at too high a moisture content heats up and supports growth of molds. This leads to a loss of feeding value. To reduce the time of exposure, curing in the field combined with forced-air drying in a barn has distinct advantages, particularly in the more humid areas of Canada.

Alfalfa stored as silage is becoming increasingly popular because more of the nutrients in the crop are preserved in silage than in hay. However, ensiling green material with more than 70% moisture leads to leaching losses and possibly to incorrect fermentation. Because nutrient loss is at a minimum, production of wilted silage (60–70% moisture) or haylage (45–60% moisture) has become the most popular harvesting and storage system. As the moisture content of the ensiled material decreases, increased attention must be paid to firm packing in the silo to exclude air; otherwise significant storage losses of nutrients and digestibility of the silage can occur. Crops that have a naturally high level of soluble carbohydrates, such as corn, ferment rapidly, producing a good deal of lactic acid, a low pH, and a high-quality silage. However, alfalfa has a low level of carbohydrates and thus does not lend itself as readily to rapid and good natural fermentation. Also, the high protein level acts as a buffer against the desired rapid lowering of pH for good fermentation. Additional carbohydrates may be added from very diverse sources: cereal grains, dried whey, dried beet pulp, and molasses. For example, carbohydrates in the form of molasses (2–5%) or grain (5–15%) have been recommended and used in alfalfa silage for more than 50 years. All these materials improve the fermentation pattern and the feeding value of alfalfa silage.

Pasture

Beginning with its Asiatic origin as a range plant, alfalfa has long been recognized as a superior pasture legume for many classes of farm livestock. The main advantages of alfalfa are:

- High carrying capacity and high dry-matter and protein yields.
- Outstanding animal performance resulting from high voluntary intake.
- Excellent as a source of calcium, magnesium, and phosphorus.
- Drought resistance and recovery when moisture becomes available.
- Long life as a perennial.
- High yield potential on irrigated land.
- No requirement for nitrogen fertilizers, as it obtains its own by symbiotic nitrogen fixation.

Alfalfa offers greater flexibility for the livestock producer than most other pasture legumes. Because of its upright growth habit and rapid recovery, it

may be harvested as hay, silage, or haylage, as well as used for pasture. This flexibility is particularly important in Canada where stored feeds are utilized for portions of the year. Alfalfa is a long-lived perennial and persists for many years if managed properly. In addition, its drought resistance provides a more uniform seasonal growth pattern than most other legumes and grasses grown in Canada. The relatively recent development of creeping-rooted and rhizomatous pasture types of alfalfa has been important in expanding its usefulness as a pasture crop. The underground crown of the creeping-rooted alfalfas is less subject to the extremes of the cold aboveground winter temperatures and to damage from animal trampling and machine travel.

Alfalfa plants require rotational grazing with a 35- to 42-day recovery period to maintain good stands for more than 2 or 3 years. Continuous grazing, unless at a light stocking rate, inevitably results in stand losses in all areas. Autumn recovery growth must occur before killing frost in order to maintain stands.

Alfalfa may cause bloat in ruminant animals on green pasture. In addition to actual losses from bloat, an even greater economic loss occurs because the fear of bloat limits use of this high-yielding legume in pasture. Alfalfa is often grown in mixture with adapted local grasses, so that grass forms at least half the mixture, to avoid problems of bloat. Other precautions are to avoid grazing immature stands; never to turn hungry animals out into lush stands of legume but rather to let them fill up first with a dry roughage; and to send chronic bloaters to the feedlot. The ultimate solution will be the development of bloat-safe alfalfa cultivars. Research and breeding efforts toward this objective have high priority among the research investigators of Agriculture Canada.

Dehydrated products

The high quality of alfalfa is best retained when it is processed into dehydrated products. These include cubes, pellets, and leaf protein concentrate, all of which are marketable on the basis of consistent quality of protein and provitamin A content. Their use makes it easier to mechanize mixing and feeding operations and ensures full use of the plant material produced.

Production of dehydrated products is not an on-farm operation but a factory-type enterprise. The enterprise must, however, be closely associated with farm production, because the cost of hauling the alfalfa from field to factory determines the economics of the operation.

Production for dehydration offers several advantages to alfalfa growers. They include quick crop removal regardless of weather conditions, no trampling of regrowth by livestock, costs of labor and harvest equipment met by the processor, no bales or stacks where weeds may develop, and sale as a contract cash crop.

"Alfalfa dehy" in maintenance, grower, and finishing rations for cattle and sheep is comparable to other protein supplements for rate of gain and feed conversion. For horses it is highly regarded as a source of protein, minerals, and particularly calcium and vitamins.

Cubes and pellets are basically a packaging of hay, which reduces losses of plant material and aids mechanization, transportation, and marketing. However, production of leaf protein concentrate (LPC) entails separation of pro-

tein concentrates from whole-plant juice that has been pressed out by rupturing the cells of the green plant material. This is a factory-type operation that produces a product suitable for human consumption. LPC production is at the stage of research and pilot plant operation, but it may become a commercial reality in the current century.

Soil improvement

Alfalfa is seldom used exclusively for a cover or a green manure crop, yet it is recognized as one of the most important soil-improving crops when used in rotations. Its deeply penetrating taproots open up the subsoil, and when the roots decay numerous channels are formed that improve the circulation of air and the percolation of water.

Alfalfa, when properly inoculated, requires no fertilizer nitrogen. Atmospheric nitrogen in the soil spaces is fixed by bacteria in the nodules and is used by the plants. Thus, when the crop is used as a ''green manure'' it replenishes the soil reserves of nitrogen, other plant nutrients, and organic matter. These conditions result in more productive soils that also have improved structure and drainage and that require less energy to till. Alfalfa can gather considerable quantities of plant nutrients from the subsoil. When the crop is turned under and decomposes, the nutrients that are liberated are concentrated in the upper layer of the soil. Succeeding shallow-rooted crops can then use these nutrients, which otherwise would not have been available.

Seed production

Successful production of alfalfa seed depends on cross-pollination by bees (Figure 6). Several bee species, including honey, bumble, and alkali bees, have been used as alfalfa pollinators throughout the world, but they have been used with little success in Canada. Some species of native leafcutting bees are our most effective pollinators, but their numbers have declined as their normal habitats were disturbed or destroyed by agricultural activities. At present, few areas support enough native bees to pollinate alfalfa adequately.

Fortunately, the introduction of the alfalfa leafcutting bee, *Megachile rotundata* (Fabricius), of Eurasian origin, has revived the alfalfa seed industry in Canada. Use of the alfalfa leafcutting bee as a pollinator has made alfalfa seed production a highly specialized agricultural industry. The seed producer, unless he uses custom-pollinating services, must become expert not only in managing alfalfa seed stands but also in managing the bees to pollinate them.

Apart from the value of the seed crop, the bees themselves are a valuable commodity. They require an investment in equipment and facilities to be managed properly and profitably. Among the costs to be considered are those relating to storage and incubation of bees, control of their parasites and predators, and construction of hives and shelters. The population of bees can be increased in favorable seasons, and there is generally a ready market for surplus bees. Income from the sale of bees is often equal to that from the sale of seed.

Management of the alfalfa leafcutting bee requires close adherence to a set annual routine. The bees are overwintered as cocoons stored at a temperature of about 4°C. They are then incubated for a period of about 3 weeks at

30°C, their emergence being timed to coincide with the flowering of the alfalfa crop. After a female emerges from her cocoon, she mates, begins building a cell made from leaf cuttings, and deposits an egg in the cell. She constructs successive cells in tunnels that are formed from grooved boards of laminated wood or polystyrene (Figure 7). These nesting materials are grouped in shelters placed at intervals in the field to be pollinated (Figure 8). For intensive production of alfalfa on irrigated land, about 50 000 bees per hectare are provided, and each shelter serves about 1.2 ha. Fewer bees are required for dryland seed production. The bees pollinate the alfalfa flowers as they collect pollen and nectar, which serve as food for the larvae that subsequently develop within the cells. The full-grown larva spins a cocoon in its cell. At the end of the season the cells are removed from the tunnels and are stored over the winter to complete the cycle.

The management requirements of the alfalfa crop for seed production differ from the requirements for forage production. Stands should be sparser than for forage because crowding of plants results in lower seed yields. Optimum plant spacing can be achieved by establishing the crop in rows. Space rows at least 60 cm apart under irrigation; wider spacings are advisable on dryland. Density of plants within the rows should also be kept low: at 60-cm row spacings, a seeding rate of 1 kg/ha will give a thick enough stand for seed production. Even with row spacing and thin seeding a stand may become too dense within the first 2 years after establishment, and so some form of thinning is necessary. Row spacings and thin stands make it easier not only to maintain optimum soil moisture but also to apply herbicides, insecticides, and drying agents more effectively.

Because of the high value of both the seed crop and the leafcutting bees, a large proportion of Canada's alfalfa seed production is on irrigated land. Irrigations should be scheduled for application before the bloom stage, to maximize flowering, but should be restricted during pod and seed formation to discourage new vegetative growth.

Weed control is of critical importance in alfalfa seed fields. Stands for seed should be established only on land free from troublesome perennial weeds such as Canada thistle, sow-thistle, and quack grass. Most weeds can be controlled by a combination of row cultivation and use of herbicides. Current recommendations should be obtained from a provincial extension or weed specialist. Seed yields may be seriously reduced by improper choice and application of herbicides.

Insect pests, including alfalfa weevils, grasshoppers, lygus bugs, and alfalfa plant bugs, may damage seed crops in some years and locations. Spring burning of alfalfa seed fields can help control lygus and plant bugs but this practice can deplete soil organic matter. Several insecticides are registered for use on seed crops but should be used only when insect populations are high enough to cause economic levels of damage. Bees are very sensitive to most insecticides, and so caution must be exercised in the timing and rates of application.

Swathing is not safe in many seed-growing areas because of the problems caused by high winds. Use a drying agent such as diquat (Reglone; Chevron Chemicals), followed by straight combining. Careful attention to adjustment of settings on the combine is important, as seed can be lost in the harvesting

operation. As a general guide, the concaves should be set at 6-mm spacing and the cylinder speed set at 1800 rpm. Adjust wind controls to direct wind toward the back of the screen, because this assists separation of chaff from seed and prevents unnecessary turbulence on the screen. A round-hole 3-mm bottom screen is preferred. Combines that return unhulled seed to the cylinder to be threshed again produce the best threshing operation.

Canada produces a small proportion of its own alfalfa seed requirements. Current seed production is concentrated in the three Prairie Provinces, with the remainder (less than 5%) in Ontario and British Columbia. Potential for seed production is greatest on irrigated land in the southern prairie region, where the high daytime temperatures allow maximum flying time for the alfalfa leafcutting bees. This does not mean that seed cannot be produced profitably farther north and in other areas of Canada. Yields will be less where the flowering period is shorter and where bees are active for a shorter time each day.

Seed yields of 300–900 kg/ha can be attained under irrigation in the southern prairie region. Without irrigation, yields of 150–300 kg/ha may be considered satisfactory.

More detailed information on management of the crop and management of leafcutting bees for alfalfa seed production is readily available. Contact the Research Station at Lethbridge, Alta., or provincial extension offices, for Agriculture Canada publication 1495, *Alfalfa leafcutter bee management in Western Canada*, and for other updated information. Leafcutting bee associations in the provinces of Alberta, Saskatchewan, and Manitoba are also good sources of information on various aspects of alfalfa seed production.

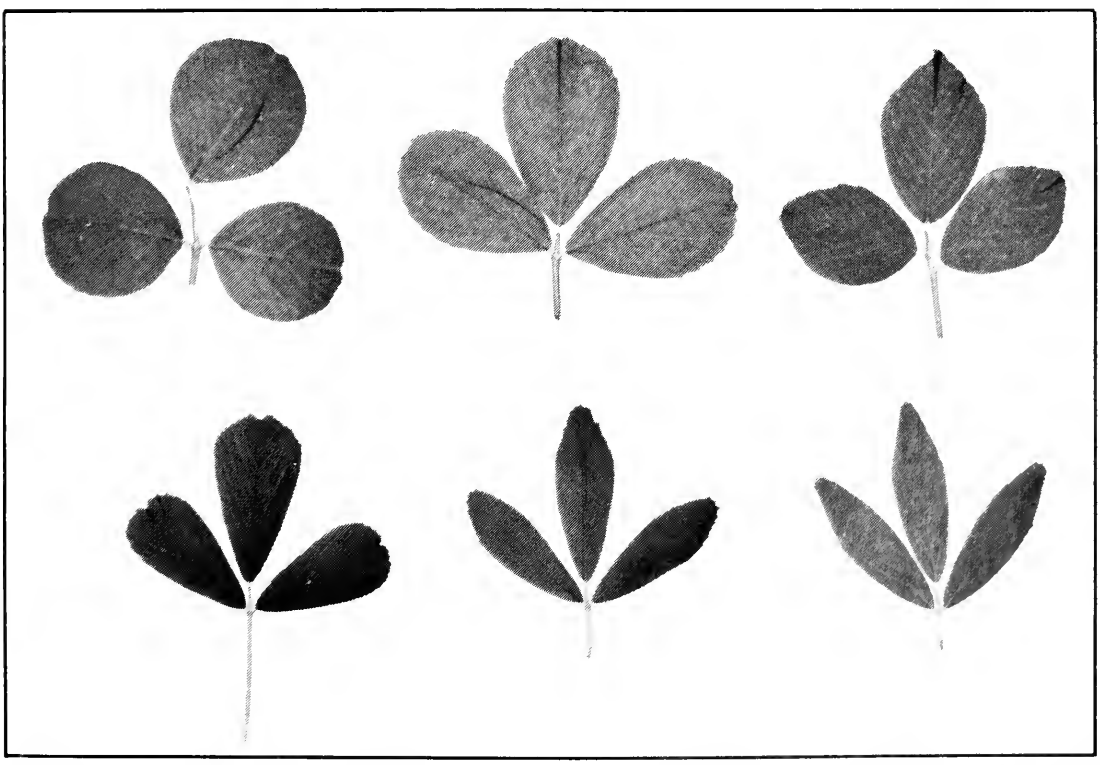


FIGURE 1 Leaf types of alfalfa, ranging from nearly round (upper left) to lanceolate (lower right).

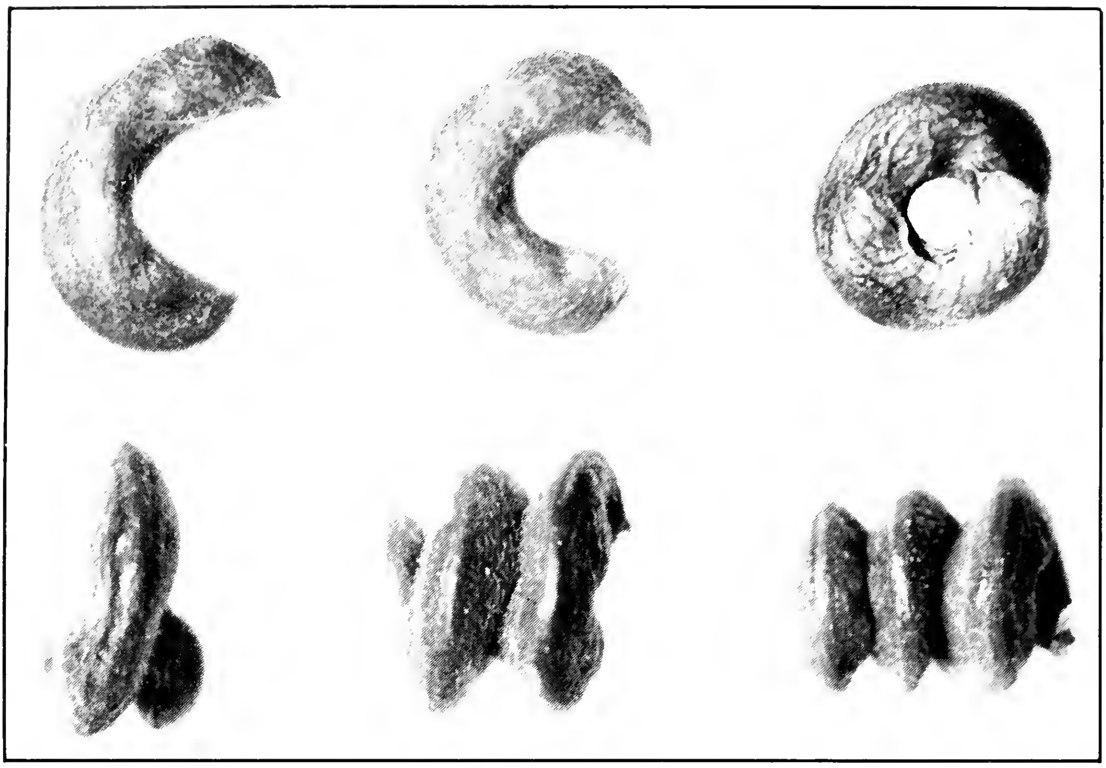


FIGURE 2 Pod types of alfalfa, ranging from the sickle type (upper left) to the triple-coil type (lower right).

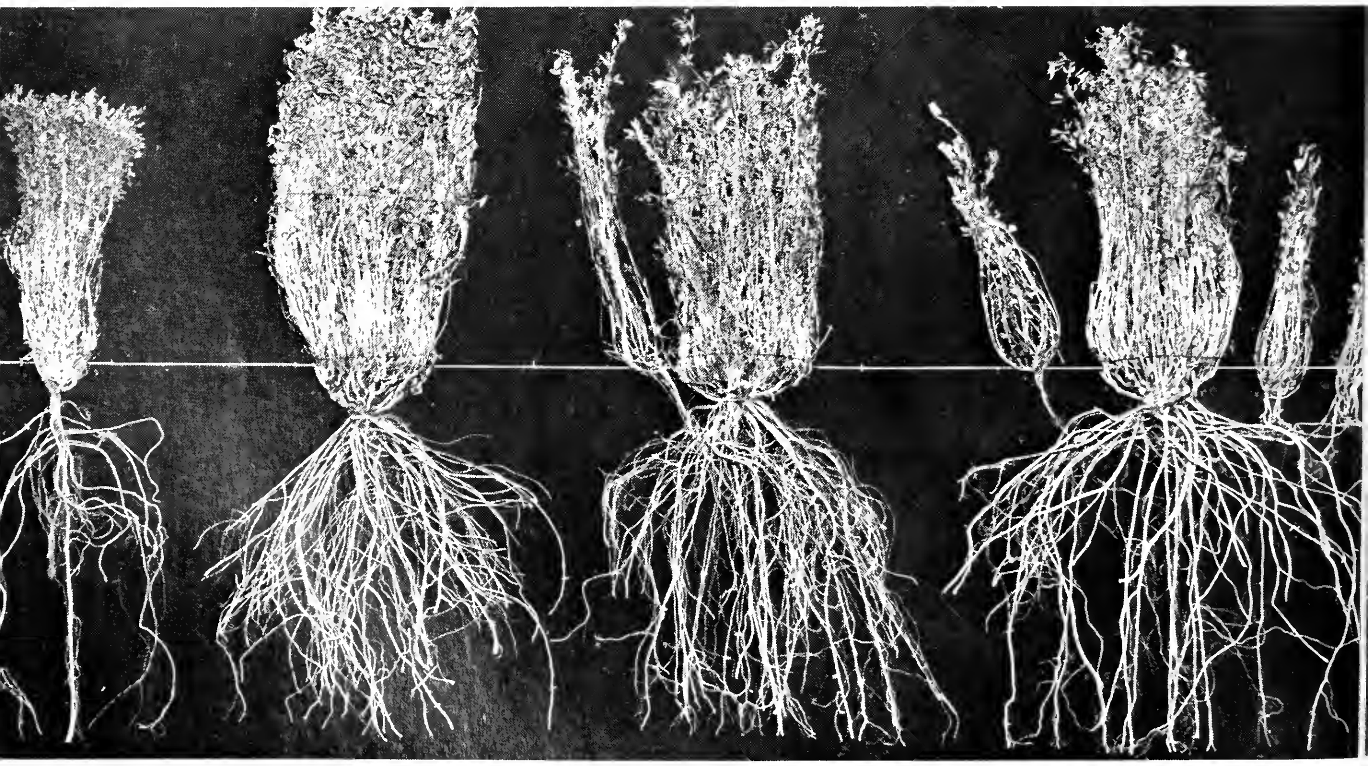


FIGURE 3 Root systems of alfalfa. Left to right: tap, branching, rhizomatous, creeping.

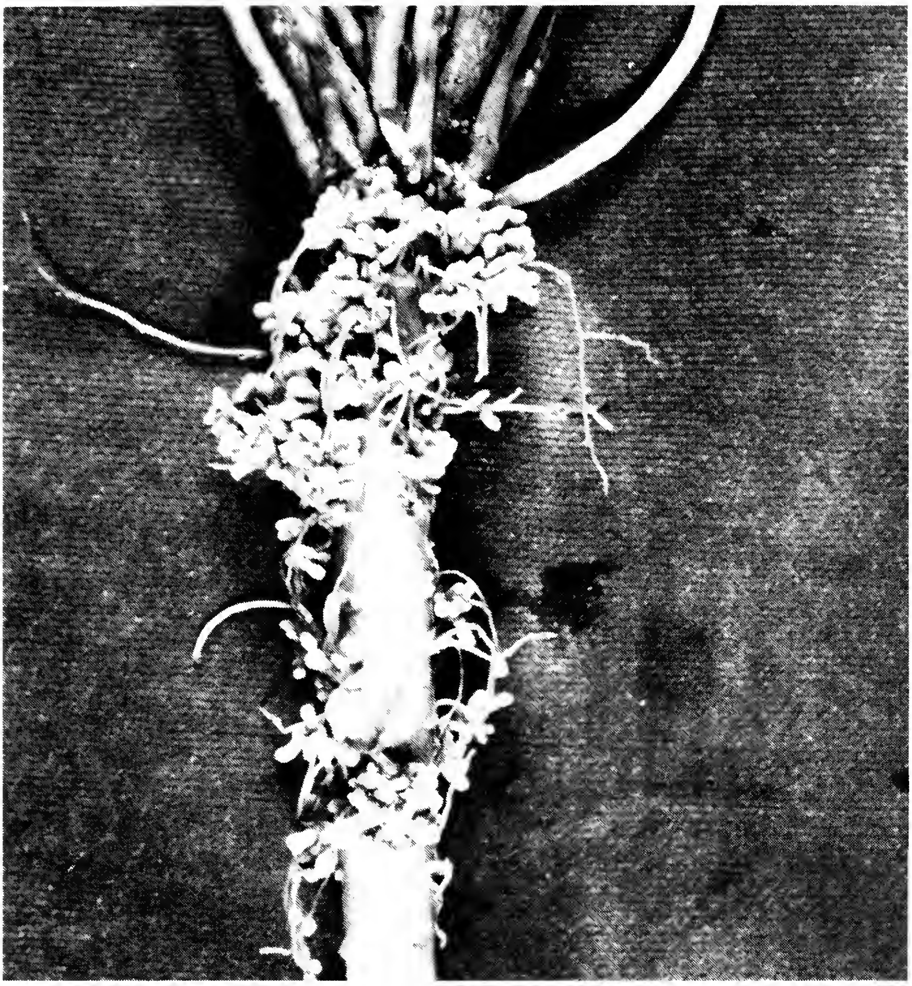


FIGURE 4 Effective nodulation on alfalfa (*Medicago sativa*) (courtesy J. Burton).

FIGURE 5 Differential winterkilling in alfalfa cultivars at Swift Current, Sask., showing (left) Rambler and (right) Du Puits.

FIGURE 6 Alfalfa leafcutting bee tripping an alfalfa flower. The flower is cross-fertilized by pollen that the bee carries from other flowers.

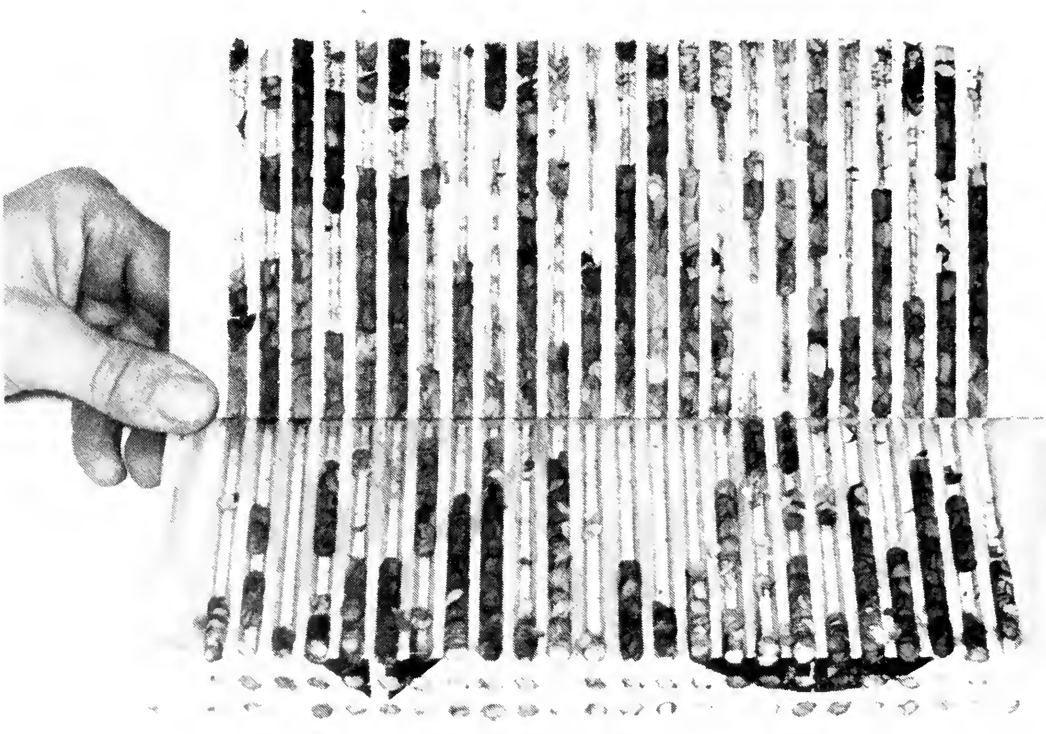


FIGURE 7 A split tunnel of a bee domicile, showing construction and cells that contain the cocoons. The tunnels are 6 mm in diameter and about 110 mm deep.

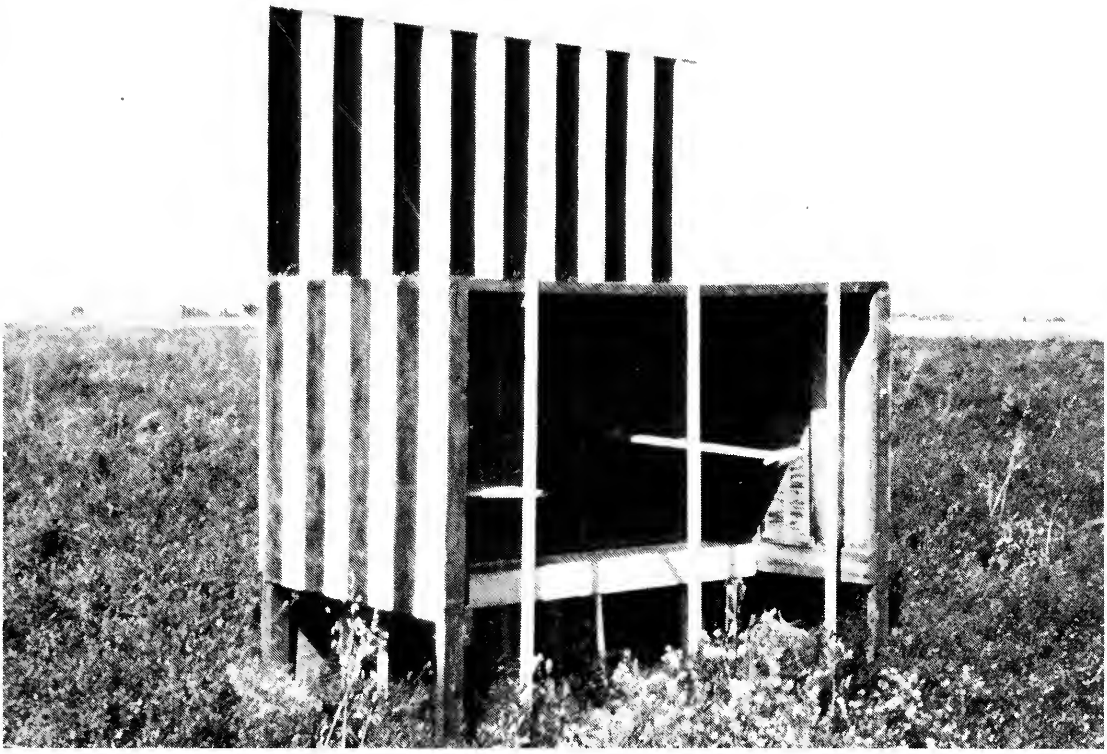


FIGURE 8 Shelter containing hives for alfalfa leafcutting bees. Vertical extension reduces wind turbulence within shelter; stripes aid bees in locating ''home'' nesting site.

Crop pests

Diseases

Alfalfa is attacked by many fungi, bacteria, viruses, and nematodes. They inflict millions of dollars worth of damage annually by reducing the yield and quality of forage. Diseases on roots and crowns of alfalfa tend to cause more severe losses than those on leaf and stem tissues because injured root and crown tissues are often very susceptible to winterkilling.

Not all the diseases described here and illustrated in Figures 9–23 are of economic importance throughout Canada. Some diseases occur rarely, if at all, in certain regions. The frequency and severity of most diseases vary from one season to another, depending on temperature, moisture conditions, and other factors. The use of resistant cultivars and proper cultural and management practices are the principal means of keeping down losses from disease. Crop rotations are helpful in reducing the incidence of many soil-borne diseases, and early cutting may reduce losses, particularly from leaf diseases. Practices that promote vigor and persistence of alfalfa stands help plants to resist or overcome diseases.

Bacterial wilt This disease (Figure 9), caused by *Corynebacterium insidiosum* (McCull.) Jensen, is most common in the irrigated districts of Western Canada. It can also be found in Ontario, but rarely elsewhere in Eastern Canada or on dryland west of Ontario. Although bacterial wilt was once a very serious

problem, it is now much less significant because highly resistant cultivars are available for all regions.

The first symptoms appear in the roots, where a yellowish orange to pale brown discoloration develops in the woody layer immediately beneath the bark of the main roots, in contrast to the creamy white appearance of healthy roots. The discoloration appears as a ring in cross section and eventually spreads throughout the woody root. Symptoms in the tops are stunting and yellowing of plants, usually in the second or third year of growth. The yellowed shoots often bear small, cupped leaves, and the tips of shoots wilt during warm weather. Plants with complete root discoloration and wilting of tops rarely survive the winter.

Crown bud rot This disease complex (Figure 10), caused by a group of organisms including *Fusarium* spp., *Rhizoctonia solani* Kühn, and other fungi, is widespread on alfalfa in Western Canada. It causes severe damage during the second and subsequent years of growth. The crown buds become infected in early spring and rot during the growing season. Dark brown or black patches develop on the bud tissue and spread to the crown and upper root areas. Poor stem development and weakened plants result in thin stands that are readily invaded by weeds. Some very hardy lines of *M. falcata* have natural resistance but there are no resistant cultivars.

Winter crown rot or snow mold This disease (Figure 11), from a low-temperature-tolerant, nonsporing basidiomycete fungus (LTB), now identified as *Coprinus psychromorbidus* Redhead and Traquair, is widespread and sometimes very destructive in central and northern areas of Alberta and Saskatchewan. It has also been reported from central British Columbia. The fungus develops under snow during the winter and early spring and damages or destroys crown tissues. Symptoms appear as a dark brown rotting of the crown and upper root tissues. Severe infestations may lead to killing of plants in large patches. The more winter-hardy cultivars with low or underground crowns may be able to escape severe damage, but there are no resistant cultivars. *M. falcata* is less susceptible than *M. sativa*.

Verticillium wilt This wilt (Figure 12), attributed to *Verticillium albo-atrum* Reinke & Berth., is the most destructive alfalfa disease in western Europe, and there is now evidence that it has become well established in the northwestern United States. Several isolated occurrences in Canada have also been recorded, the latest report indicating that it is present in the southern interior of British Columbia.

Temporary wilting of upper leaves on warm days is the early symptom of the disease, followed by wilting, yellowing, and drying out of lower leaves. There may be partial recovery of plants from wilting, but new shoots wilt rapidly. Fruiting bodies of the fungus give infected stems a grayish color, which later turns black. A dark brown discoloration develops in outer vascular tissues within the stem. Spread of the verticillium wilt fungus through infected seed can be controlled by seed treatment, but it also spreads in plant debris, and many weeds and crop plants are hosts for the disease. Cultivars with resistance have been developed in England, Sweden, France, and Denmark. Plant

breeding appears to offer hope for control of the disease if it becomes significant in North America.

Phytophthora root rot This disease (Figure 13), caused by *Phytophthora megasperma* Drechsl., occurs mainly in wet, poorly drained soils during long periods of wet weather or under excessive irrigation. It is an important disease in Ontario but has also been reported elsewhere in the country. Rotting of taproots at various depths below the soil surface is a distinctive symptom. Yellowish brown patches develop on the roots and may extend to the crown, killing the plant. Seedlings are particularly susceptible, but plants of all ages may be affected. Resistance has been bred into several alfalfa cultivars (see Table 1).

Recent work on the so-called ''alfalfa sickness'' problem in central Alberta suggests that the phytophthora root rot organism is at least partly responsible for poor growth of alfalfa on land where the crop has previously grown well during the first time in the rotation. When the crop is reseeded for the second or third time, germination is usually good but seedlings are stunted, spindly, yellowed, and poorly nodulated. The phytophthora root rot organism is one of the fungi that has been isolated from diseased areas on the roots of such seedlings. Breeding programs are in progress to develop *Phytophthora*-resistant cultivars for central and northern Alberta and Eastern Canada. The *Phytophthora* fungus is difficult to isolate and may prove to be more widespread in Canada than we know at present.

Fusarium root rot Root rots (Figure 14) caused by a number of *Fusarium* species are widespread, but they are particularly severe in Quebec and the Atlantic Provinces. The first obvious sign in the tops is curling of leaves at the edges, followed by wilting; brown stripes occur in the woody part of the root. Later damage in the root varies from small rotted areas to complete breakdown of the root and crown. The rot often develops after root or crown tissues have been injured. No resistant cultivars are available.

Brown, or winter, root rot This disease (Figure 15) is caused by a mold tolerant of low temperatures or by a snow mold, *Phoma sclerotioides* (synonym, *Plenodomus meliloti*). It is widespread in the northern parklands, the Peace River region and the Yukon: the farther north, the more serious is the disease. In the north, brown root rot can be more damaging than winter crown rot, with which it is strongly associated. Root rot injury is characterized by roughly circular sunken brown lesions, with darker margins appearing on the root surfaces, usually expanding from the place where a lateral root emerges. The lesions expand until they completely rot through the root. They may start anywhere on the taproot, from near the crown to 60 cm deep or deeper. Small gray-black fruiting bodies dot the surface of well-developed lesions. Dead, shrunken roots become grayish and brittle or softly rotted from bacterial contamination. Brown root rot occurs on most legumes, but especially on sweetclover and alsike clover. It also proliferates on perennial grasses and winter cereals. Crops are therefore rotated annually for at least 3 years. Anik is the only alfalfa cultivar known to be even partly resistant. Winterhardiness, where there is adequate snow cover, is closely correlated with resistance to brown root rot.

Common leaf spot This disease (Figure 16), from *Pseudopeziza trifolii* (Biv.-Bern.) Fckl. f. sp. *medicaginis-sativae* Schmiedeknecht, formerly called *P. medicaginis*, occurs wherever alfalfa is grown. Like many other leaf diseases of alfalfa, it tends to be most damaging in Eastern Canada and is rarely of economic significance in the more arid west. Surveys in Quebec have indicated that common leaf spot is the most destructive of several leaf diseases. It is characterized by small, circular, brown to black spots on the leaflets. A somewhat paler, raised disk develops in the center of older spots. Infected leaves turn yellow and drop prematurely as the disease progresses. When the disease is prevalent, early cutting helps to reduce losses.

Lepto leaf spot This type of leaf spot (Figure 17), attributed to *Leptosphaerulina briosiana* (Pall.) Graham & Luttrell, is sometimes more damaging than common leaf spot. It has been known to reach epidemic proportions in the eastern and central United States. Surveys in Quebec indicate that the level of damage caused by lepto leaf spot is similar to that caused by common leaf spot. Only young leaves become infected, and the greatest damage occurs on young growth that develops after clipping during cool, wet summers. Leaf symptoms start as small, black spots with a light surrounding halo. This "pepper spot" stage may remain unchanged or may enlarge into irregular to round "eyespots" having tan centers and dark brown borders, often surrounded by a yellowed area. The entire leaf may be killed, and the dead leaflets remain attached to the stem for some time. No effective control measures are known.

Stemphylium leaf spot The leaf spot disease (Figure 18) caused by *Stemphylium botryosum* Wallr. occurs in Eastern Canada but is usually of minor importance. Oval or irregular spots with sunken centers appear on the leaflets. These spots are generally dark brown with lighter centers, and are often surrounded by a pale yellow halo. Older spots show concentric rings, resembling a target. A single large spot on a leaflet is enough to cause leaf drop, and severe loss of leaves can occur. There are no resistant cultivars but there are differences in susceptibility among existing ones.

Spring black stem This disease (Figure 19), from *Phoma medicaginis* Malbr. & Roum., is found in virtually all areas of Canada where alfalfa is grown, and is favored by cool, moist weather. Small, irregular, dark brown spots develop on lower leaves. The spots merge as they increase in size and the leaves turn yellow and drop off. Spots developing on stems turn black, enlarge and merge, sometimes girdling and killing young shoots. Seed production stands are often severely affected as the disease has a full growing season to develop. It overwinters on dead alfalfa stems and leaves; hence burning crop residue is an effective form of control in seed and hay fields.

Yellow leaf blotch Yellow leaf blotch (Figure 20), caused by *Leptotrochila medicaginis* (Fckl.) Schüepp, like common leaf spot is present in all major alfalfa-producing areas, but it is generally considered less damaging. However, surveys in central and northern Alberta show that losses attributed to yellow leaf blotch are about equal to losses caused by several other leaf and stem diseases combined. Symptoms appear as elongated yellow blotches that develop parallel to the veins of the leaflets, sometimes extending from the midrib to the leaf

margin. Numerous very small orange to black fruiting bodies develop in linear patterns on the upper leaf surface of diseased areas. Blotches appear occasionally on stems. As with most other leaf diseases, early cutting before much loss of leaves occurs tends to reduce the incidence of disease on regrowth.

Downy mildew This mildew (Figure 21), from *Peronospora trifoliorum* de Bary, is a cool-weather disease that is widely distributed in Canada's alfalfa-growing areas, but it usually does not cause severe damage. Symptoms include a light green coloration of upper leaves, dwarfing of shoots, and twisting and curling of leaves at the stem tips. A fine gray fungal growth develops on the underside of the leaves. Infected stands should be cut; in warm, dry weather the regrowth will probably escape further damage.

Stem nematode The stem nematode *Ditylenchus dipsaci* (Kühn) Filipjev is responsible for one of several diseases in alfalfa caused by the group of organisms known as nematodes, or eelworms. Significant losses from this disease (Figure 22) in Canada have been confined to the irrigated districts of southern Alberta. The nematode invades crown buds, which become swollen and break off easily. Shoots from infected buds are severely dwarfed, with thickened nodes and shortened internodes. Infected shoot tissues become wrinkled and discolored. Scattered infected plants may display the "white flag" symptom, in which one or more affected shoots are completely devoid of green color and usually somewhat small in size. Resistant cultivars provide the only practical means of control. The stem nematode is a carrier of wilt bacteria and has a decided influence on the development of the wilt disease in both wilt-susceptible and wilt-resistant alfalfa cultivars. Trek is the only stem-nematode-resistant cultivar licensed in Canada.

Northern root-knot nematode This nematode, *Meloidogyne hapla* Chitwood, is widespread in Eastern Canada. It parasitizes the roots of alfalfa plants, causing a characteristic galling (Figure 23). Symptoms include dwarfing of plants, reduction of stands, and galling and excessive branching of roots. Young seedlings may die as a result of heavy infection, even though roots fail to show galling. Bacterial wilt and crown and root rot diseases are more common when alfalfa is infested with this root-knot nematode. Breeding for resistance should eventually lead to development of resistant cultivars adapted to areas of Canada where this nematode affects alfalfa production.

Root-lesion nematode The nematode *Pratylenchus penetrans* (Cobb) Filipjev & Stekhoven also occurs widely in Eastern Canada. The extent of losses caused by infestation with this nematode (Figure 24) are not known, but it does contribute to reduced forage yield and a decline of stands. It feeds inside root tissues, so that the disease is not readily identified by untrained observers. The presence of the root-lesion nematode, like that of other nematodes on alfalfa, undoubtedly influences the development of wilt, root rots, and other diseases. Breeding for resistance offers promise of a measure of control. Rotations that include resistant crops may be necessary.

FIGURE 9 Bacterial wilt (*Corynebacterium insidiosum*): upper photo, healthy plant (left) and diseased plant (right); lower photo, cross sections of healthy root (left) and diseased roots (center, right) (courtesy F. I. Frosheiser).

FIGURE 10 Crown bud rot (*Fusarium* spp., *Rhizoctonia solani,* etc.), which causes brown to black diseased areas on crown bud tissue and upper roots (courtesy E. J. Hawn).

FIGURE 11 Winter crown rot (nonsporing, low-temperature-tolerant basidiomycete fungus, *Coprinus psychromorbidus*) showing increasing severity of damage (courtesy J. D. Smith).

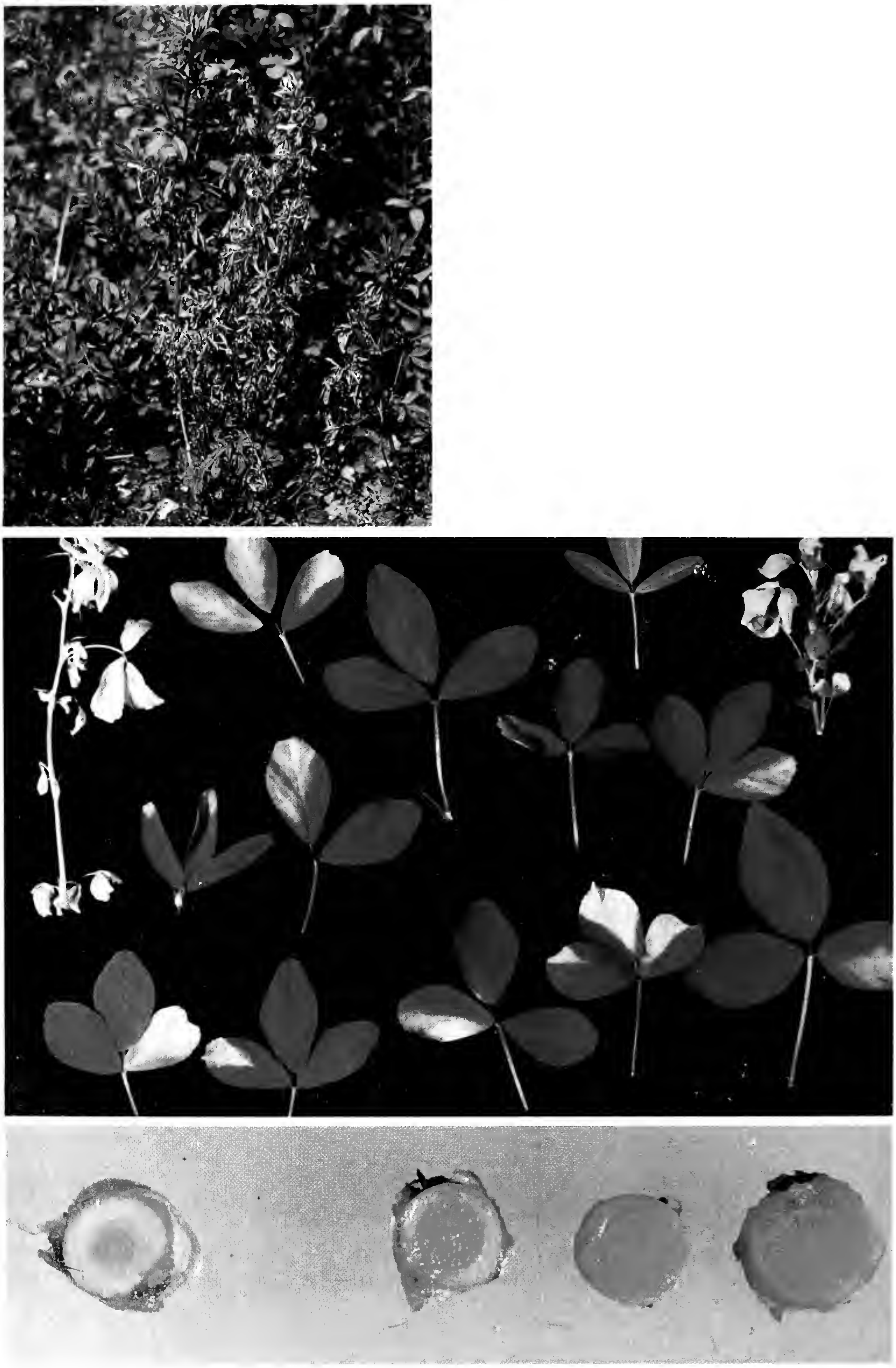


FIGURE 12 Verticillium wilt (*Verticillium albo-atrum*). Top: field plant; center: leaf and stem symptoms; bottom: healthy root (left) and three diseased roots (right) (courtesy M. R. Hanna).

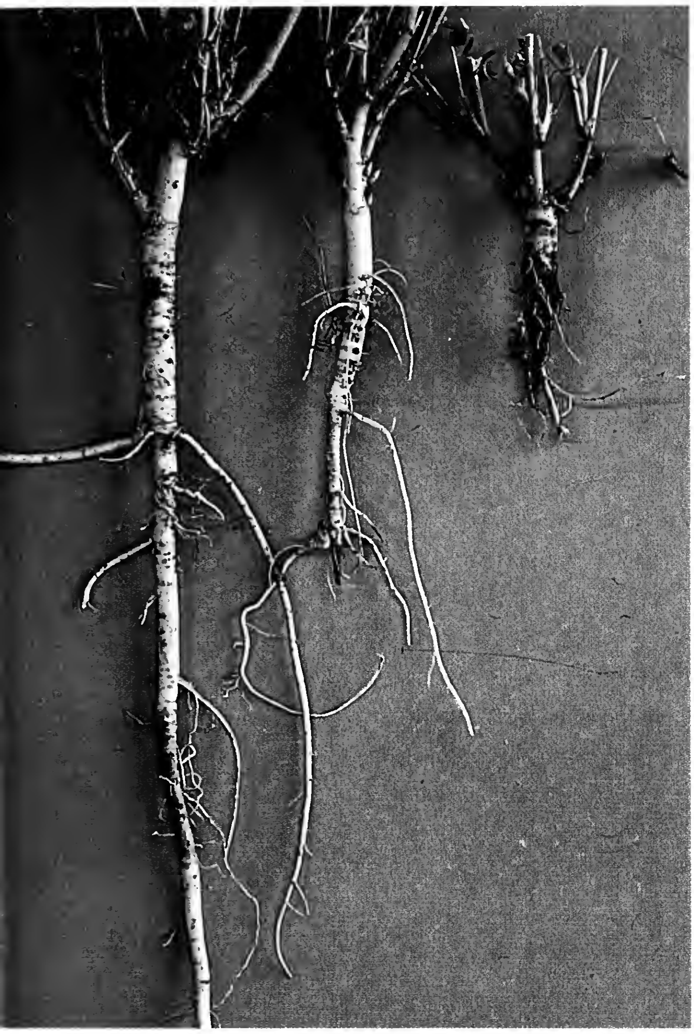


FIGURE 13 Phytophthora root rot (*Phytophthora megasperma*) showing different degrees of severity (courtesy F. I. Frosheiser).

FIGURE 14 Fusarium root rot (*Fusarium* spp.), which causes rotting of root and crown (courtesy C. Richard).

FIGURE 15 Brown root rot (*Phoma sclerotioides,* syn. *Plenodomus meliloti*) showing developed and incipient lesions on the roots and spread into the crowns (left); close-up view of a lesion (right); (courtesy J. G. N. Davidson).

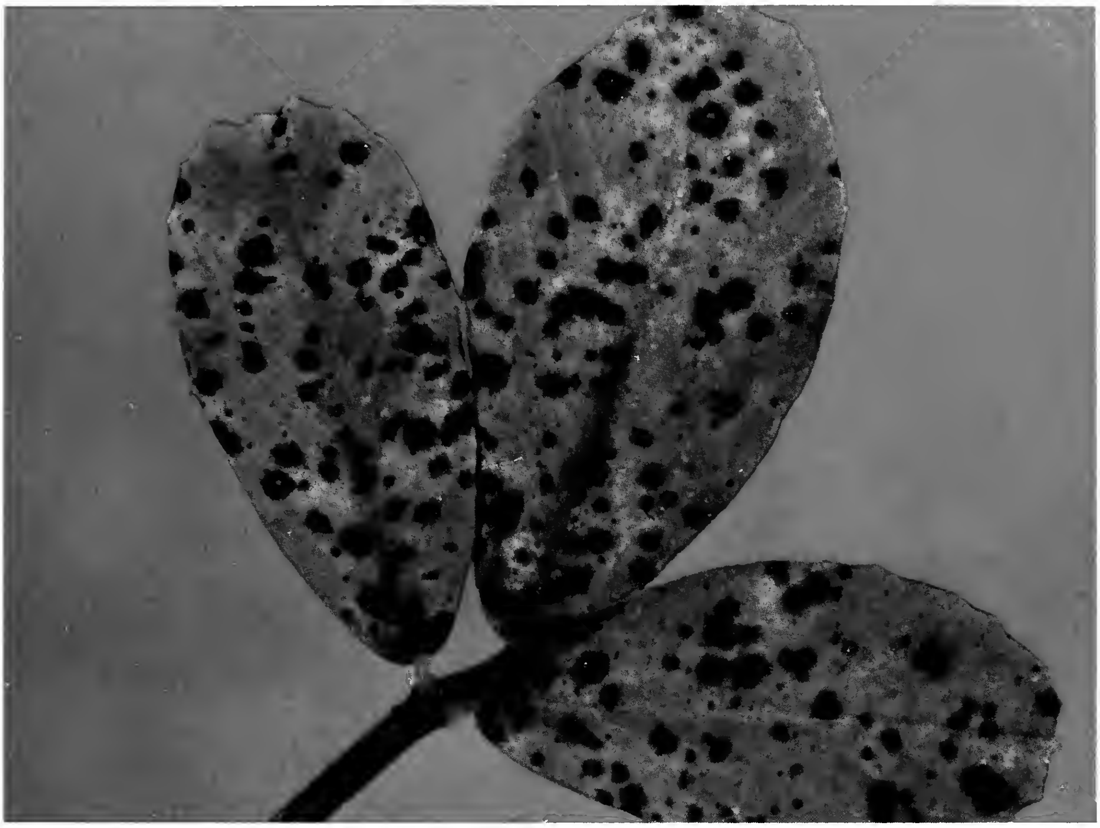


FIGURE 16 Common leaf spot (*Pseudopeziza trifolii*) with advanced symptoms (courtesy R. Michaud).

FIGURE 17 Lepto leaf spot (*Leptosphaerulina briosiana*) with typical small brown to black spots surrounded by a halo (courtesy R. Michaud).

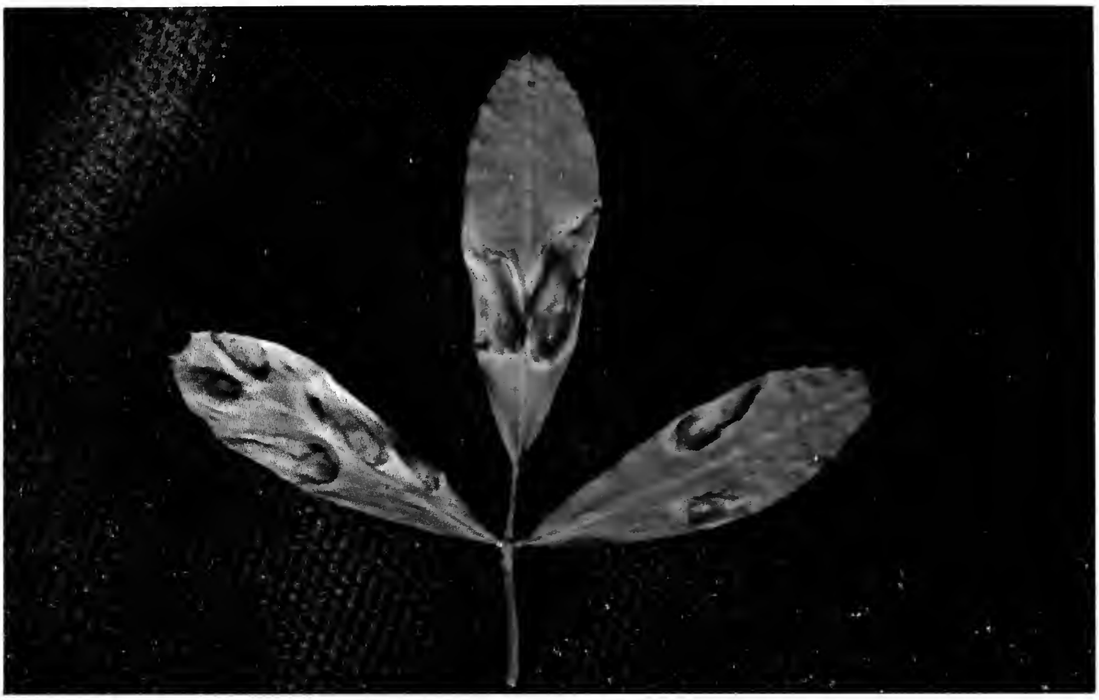


FIGURE 18 Stemphylium leaf spot (*Stemphylium botryosum*) showing large oval or irregular dark brown spots with lighter sunken centers (courtesy F. I. Frosheiser).

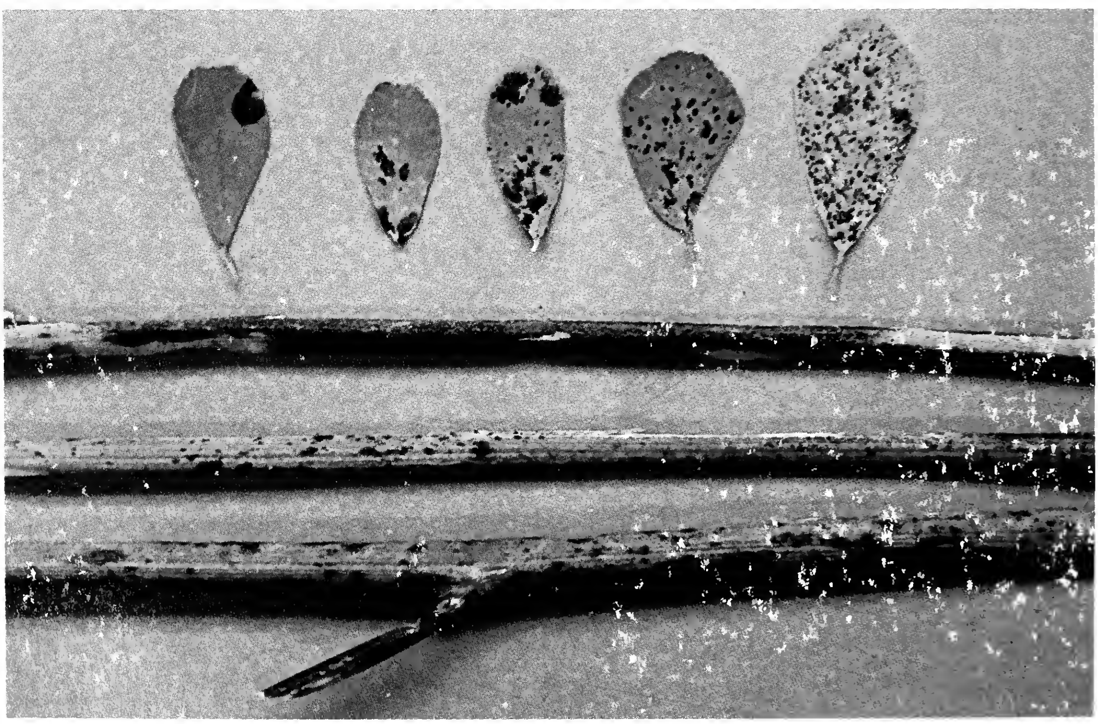


FIGURE 19 Spring black stem (*Phoma medicaginis*) showing stem and leaf spots (courtesy F. I. Frosheiser).

FIGURE 20 Yellow leaf blotch (*Leptotrochila medicaginis*) with elongate yellowed blotches parallel to leaf veins in early stages (top) and later stages (bottom) (courtesy W. B. Berkenkamp and D. L. Stuteville respectively).

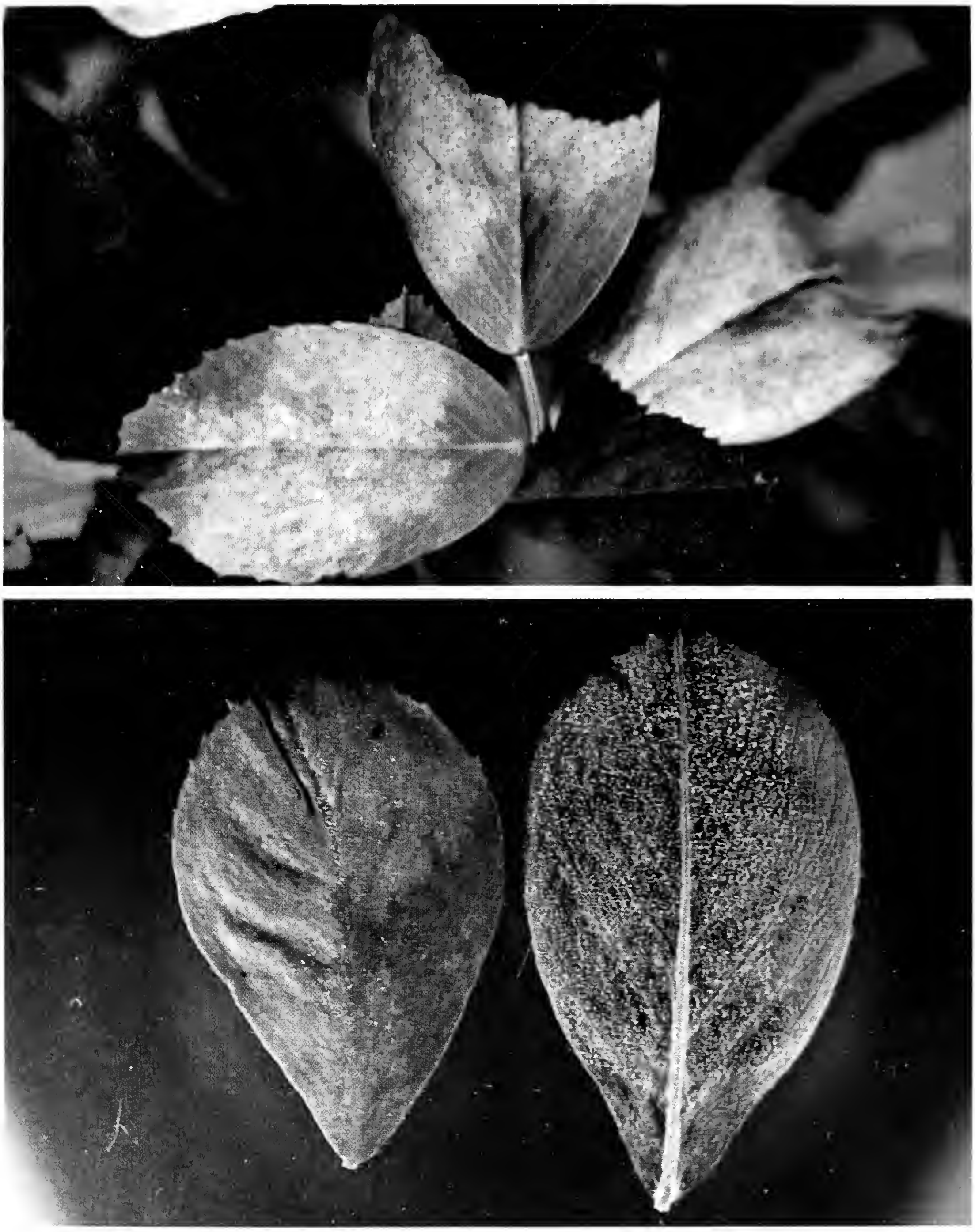


FIGURE 21 Downy mildew (*Peronospora trifoliorum*) with characteristic leaf symptoms (top) and white to purplish downy growth (bottom) on upper and lower surfaces of a leaf (courtesy W. B. Berkenkamp and D. L. Stuteville respectively).

FIGURE 22 Stem nematode (*Ditylenchus dipsaci*): healthy root (left) and diseased root (right) showing discolored, severely dwarfed stems, swollen nodes, and short internodes (courtesy E. J. Hawn).

FIGURE 23 Northern root-knot nematode (*Meloidogyne hapla*): healthy plant in center, with diseased plants on either side showing symptoms of excessively branched roots with massive galling (courtesy R. N. Peaden).

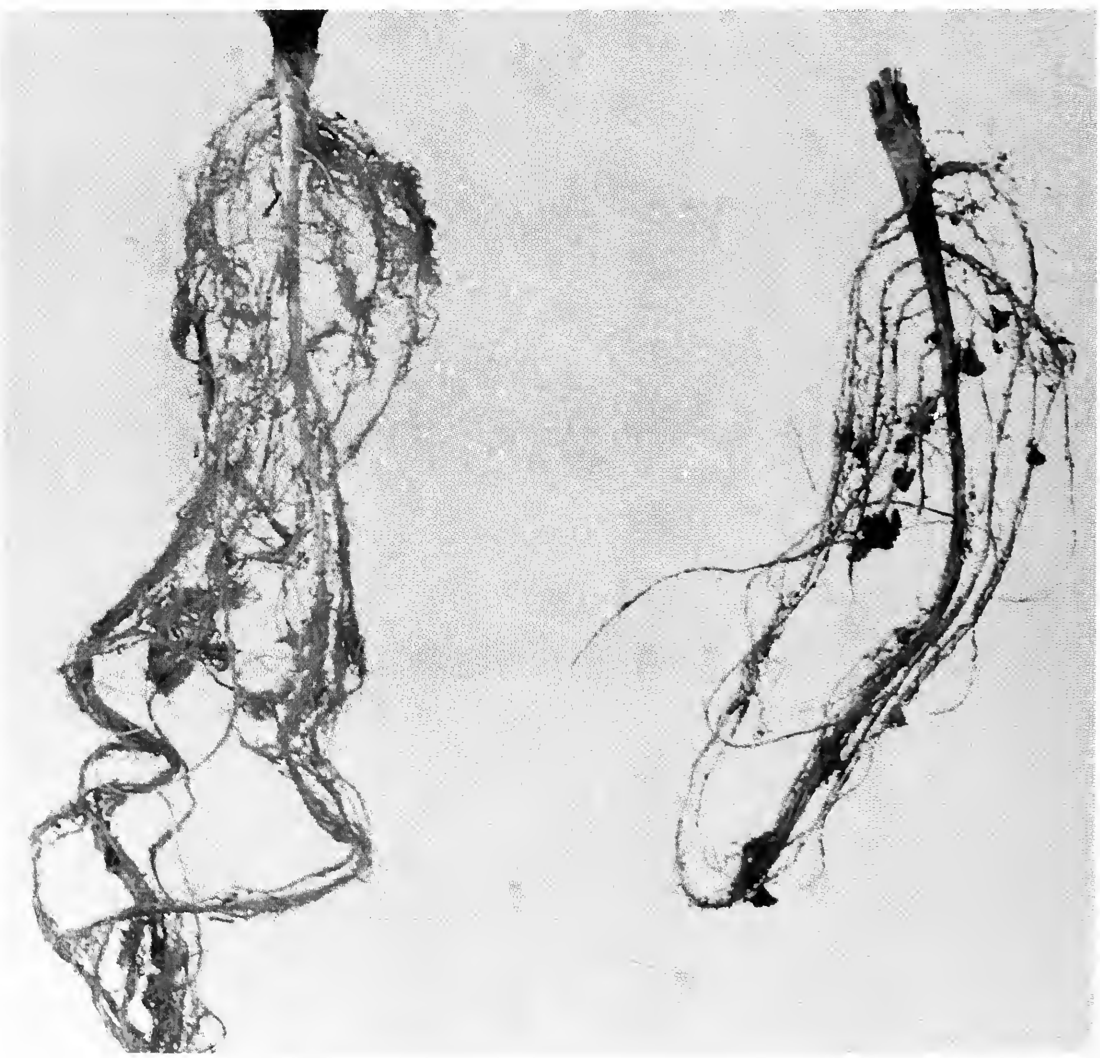
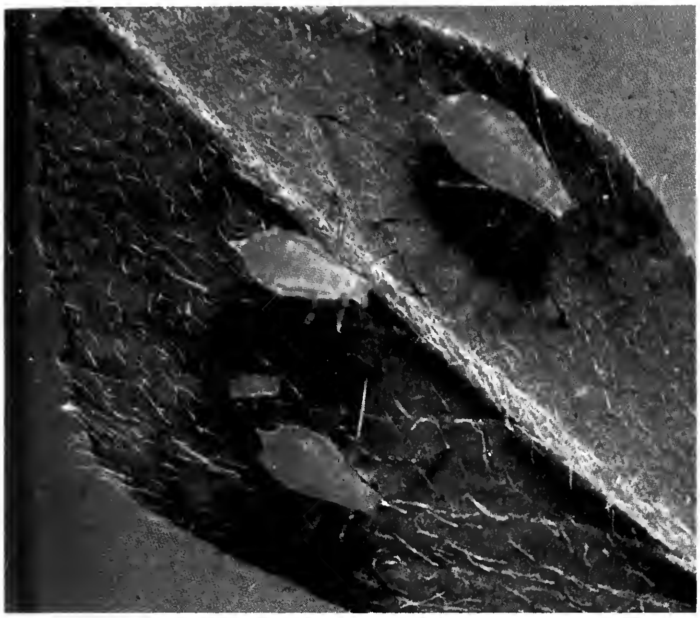


FIGURE 24 Root-lesion nematode (*Pratylenchus penetrans*) showing healthy alfalfa root (left) and diseased root (right) with greatly reduced feeder rootlets and discoloration of rootlets and tap root (courtesy C. B. Willis).



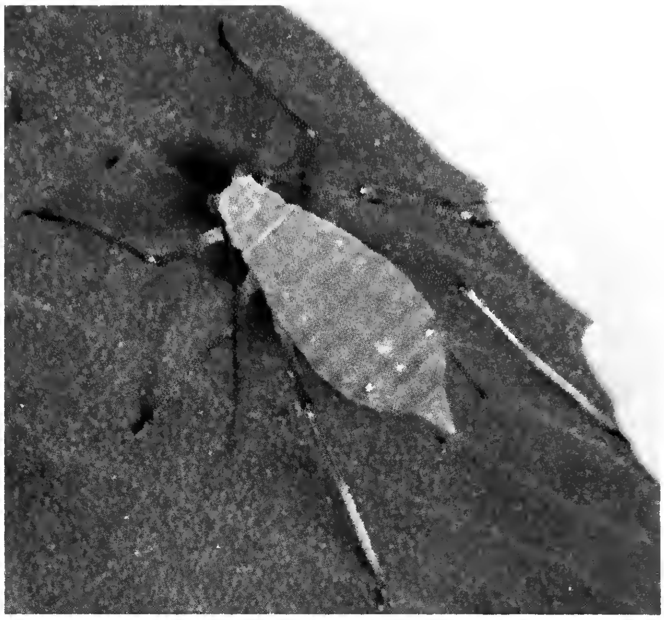


FIGURE 25 Pea aphid (*Acyrthosiphon pisum*) on alfalfa leaf: left photo, insects at various stages of development; right photo, enlarged adult (courtesy C. H. Craig and A. M. Harper respectively).

IGURE 26 Lygus bug (*Lygus* spp.) on alfalfa ourtesy K. W. Richards).

FIGURE 27 Alfalfa plant bug (*Adelphocoris lineolatus*) on alfalfa leaflet (courtesy A. M. Harper).

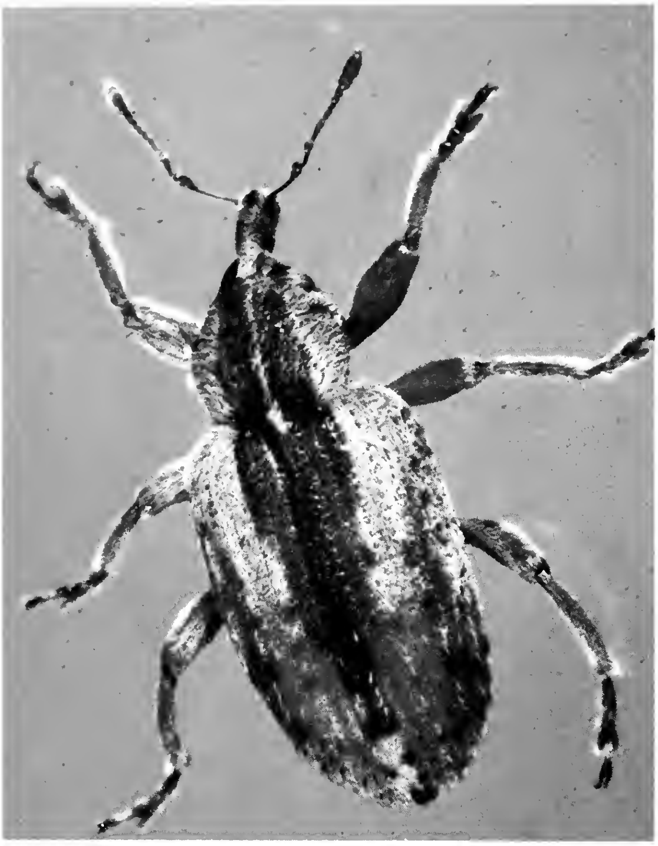


FIGURE 28 Alfalfa weevil (*Hypera postica*) adult (courtesy Entomology Department, Purdue University).

FIGURE 29 Alfalfa weevil larvae feeding on alfalfa leaflet (courtesy R. R. Kriner).

FIGURE 30 Alfalfa blotch leafminer (*Agromyza frontella*) larvae and pinhole feeding punctures (courtesy R. Michaud).

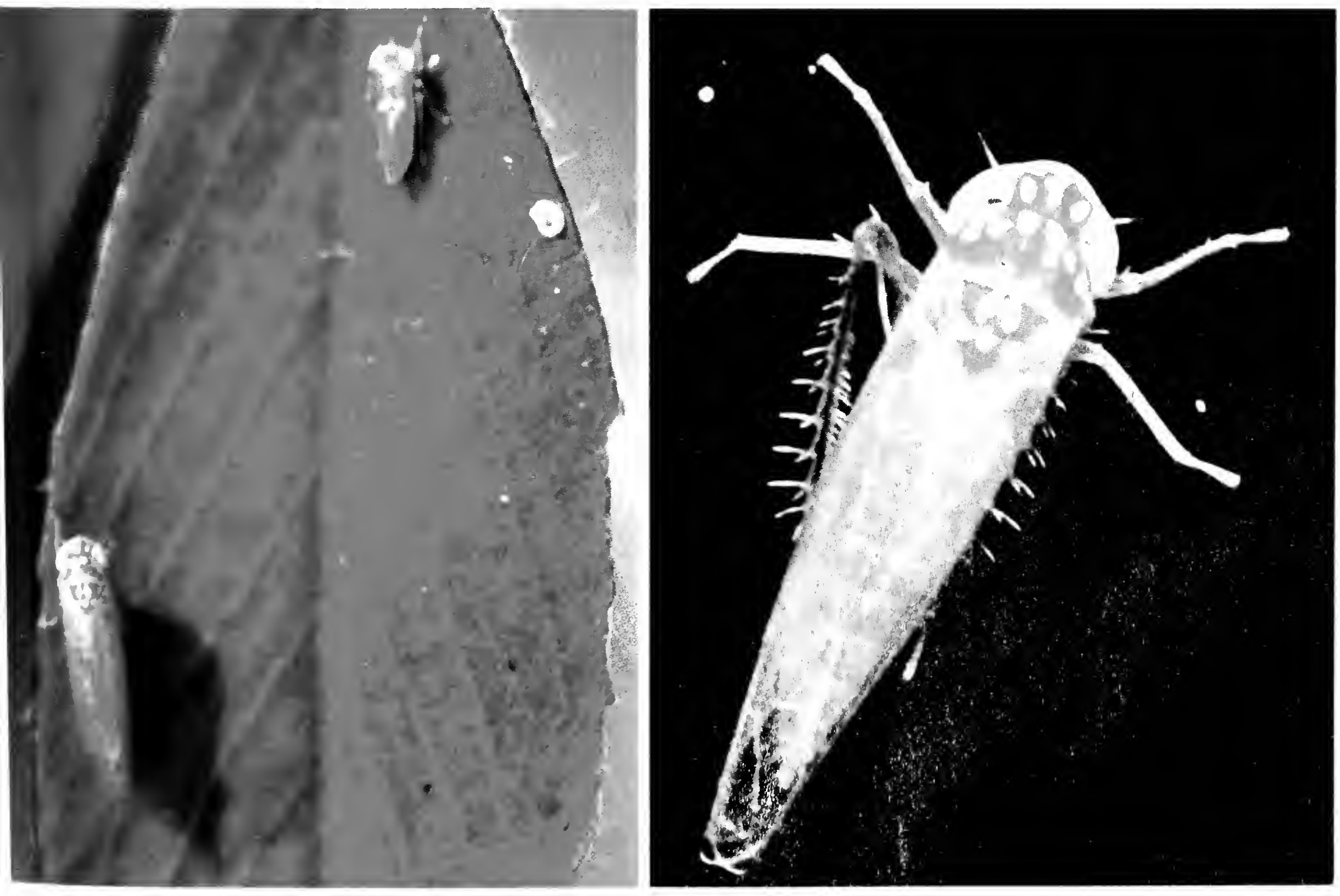


FIGURE 31 Potato leafhopper (*Empoasca fabae*). Left: adult and nymph on alfalfa leaflet; right: enlarged adult (courtesy G. R. Manglitz and R. R. Kriner respectively).

FIGURE 32 Characteristic symptoms of leafhopper burn (left) and puncture holes (right) caused by potato leafhopper feeding (courtesy R. A. Byers and R. Michaud respectively).

FIGURE 33 Grasshopper on alfalfa (courtesy R. E. Underwood).

Harmful insects

Alfalfa is very palatable, not only to livestock but also to many insects. All insects that adversely affect the health of a plant can reduce forage or seed yields. Some insects attack the flowers or seeds of alfalfa but cause little direct harm to the vegetative parts. Most harmful insects can be controlled by applying insecticides of various kinds, but precautions must be taken to avoid leaving residue on pasture and forage, or destroying pollinators or useful parasites. Some injurious insects can be controlled by combinations of cultural, biological, and chemical methods.

As an aid for visual identification of injurious insects and associated plant symptoms, illustrations are provided in Figures 25–33.

Pea aphid The pea aphid (Figure 25), *Acyrthosiphon pisum* (Harris), is found throughout Canada and is the most common insect found on alfalfa. Pea aphids are small (1–2 mm long), green, soft-bodied insects that do not move around much on the plants. All the young are wingless but adults may be winged or wingless. They feed by piercing the plant tissue and sucking the sap. Symptoms include white punctures or markings on leaves caused by aphid feeding; stunted or spindly, brittle growth of plants; and yellowing and dropping of leaves. Pea aphids are more important on irrigated land than on dryland. Heavy infestations in localized areas may cause severe damage. Infestations are greatest in cool weather during the spring and early summer. First-cut alfalfa is usually not extensively damaged, but damage to the second crop may be severe as populations reach peaks in late July or early August. Pea aphids are controlled through management of stands to maintain vigorous, healthy growth, through treatment with insecticides, and through reliance upon natural parasites to reduce infestations. Damage may be reduced by early cutting of forage.

Plant bugs The complex of plant bugs comprising *Lygus* spp., *Adelphocoris* spp., and *Plagiognathus* spp. (Figures 26, 27) is one of the main pests of alfalfa seed crops, but not of alfalfa forage crops. Symptoms include poor blooming; blasted, whitish and dry flower buds; and dropping of flowers before they are fully open. Plants are often stunted, dry, and brown. A poor seed set results and shriveled seed is present at harvest. Control methods include burning of alfalfa stubble and straw early in spring to destroy eggs of *Adelphocoris* and adults of *Lygus.* In burned fields, insecticides can be applied as the crop is coming into bloom, whereas in unburned fields insecticides can be applied as the crop is coming into bud. In both cases the insecticide applications should be made before the leafcutting bees are in the field.

Alfalfa weevil This insect (Figures 28, 29), *Hypera postica* (Gyllenhal), occurs in Ontario and Alberta and is one of the most serious pests of alfalfa. The adult is a brown snout beetle with a stripe down the middle of its back. The larva has a black head, yellowish green body, and three white stripes down its back. Young larvae feed first on the growing plant tips and then more and more upon opened leaves, which soon becomes dry skeletons and take on a grayish to whitish cast. The larvae also feed upon flower buds and can greatly reduce seed yields. Timely cutting of the first crop interrupts weevil development and

destroys most of the eggs, larvae, and pupae before they mature. Some parasites reduce weevil populations, but when populations are left unchecked, properly timed chemical control may be necessary, especially in seed fields.

Alfalfa blotch leafminer This leafminer (Figure 30), *Agromyza frontella* (Rondani), is a relatively new pest in Eastern Canada. It overwinters as a pupa and emerges as a small adult fly in late May or early June. Its presence is best detected by numerous pinhole punctures in leaflets made by the feeding adults. Eggs are laid in the alfalfa leaflets and the larvae feed between the leaf surfaces, forming an irregular blotch pattern. There are at least three generations a year in Eastern Ontario, about 30 days apart. Damage to the foliage results in nutritional loss through mining or leaf drop. Severe damage may be prevented by an early first cutting, but subsequent infestations do not correspond to cutting dates. For these later infestations, chemical control is effective at the pinhole stage. The extent of losses in quality and yield of forage caused by leafminer infestations has not been determined.

Potato leafhopper The potato leafhopper (Figures 31, 32), *Empoasca fabae* (Harris), is one of the more important of several leafhoppers that attack alfalfa in Eastern Canada. It is a tiny, light green, wedge-shaped insect about 2–3 mm long. The nymph is yellowish green and characteristically walks sideways. Both adults and nymphs pierce leaves and stems and suck plant juices, thus inflicting serious injury. They also transmit viruses. Symptoms appear as stunting of the plant and a yellowing or reddening of leaves in a V-shape from the center of the leaf outward. Insecticides do not prevent the disease from spreading. If potato leafhoppers are abundant on newly seeded alfalfa, spray with an insecticide.

Grasshoppers These insects (Figure 33), belonging to *Melanoplus, Camnula,* and other genera, are not consistently a serious pest of legumes, but outbreaks can occur in Western Canada. The grasshoppers can migrate from uncultivated areas into fields of alfalfa. Leaves, stems, and seed pods are completely or partly eaten, and stands become thinned from the edge inward. Both grass and alfalfa are damaged in mixtures. In Western Canada the grasshopper forecast map shows the extent and severity of grasshopper outbreaks expected the next season. For control, tillage of stubble land in the fall destroys some eggs and tillage in the spring destroys green growth (the food supply) as eggs are hatching. Chemical control is the only means of effectively controlling grasshoppers and may be necessary when the crop is threatened.

Other insects Various other insects on occasion are serious pests of alfalfa. These are the cutworms, thrips, alfalfa seed chalcid, clover root curculio, and alfalfa looper. For specific control measures see the information leaflets issued by provincial departments of agriculture.

Acknowledgments

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Conversion factors

Metric units	Approximate conversion factors	Results in:
LINEAR		
millimetre (mm)	x 0.04	inch
centimetre (cm)	x 0.39	inch
metre (m)	x 3.28	feet
kilometre (km)	x 0.62	mile
AREA		
square centimetre (cm^2)	x 0.15	square inch
square metre (m^2)	x 1.2	square yard
square kilometre (km^2)	x 0.39	square mile
hectare (ha)	x 2.5	acres
VOLUME		
cubic centimetre (cm^3)	x 0.06	cubic inch
cubic metre (m^3)	x 35.31	cubic feet
	x 1.31	cubic yard
CAPACITY		
litre (L)	x 0.035	cubic feet
hectolitre (hL)	x 22	gallons
	x 2.5	bushels
WEIGHT		
gram (g)	x 0.04	oz avdp
kilogram (kg)	x 2.2	lb avdp
tonne (t)	x 1.1	short ton
AGRICULTURAL		
litres per hectare (L/ha)	x 0.089	gallons per acre
	x 0.357	quarts per acre
	x 0.71	pints per acre
millilitres per hectare (mL/ha)	x 0.014	fl. oz per acre
tonnes per hectare (t/ha)	x 0.45	tons per acre
kilograms per hectare (kg/ha)	x 0.89	lb per acre
grams per hectare (g/ha)	x 0.014	oz avdp per acre
plants per hectare (plants/ha)	x 0.405	plants per acre